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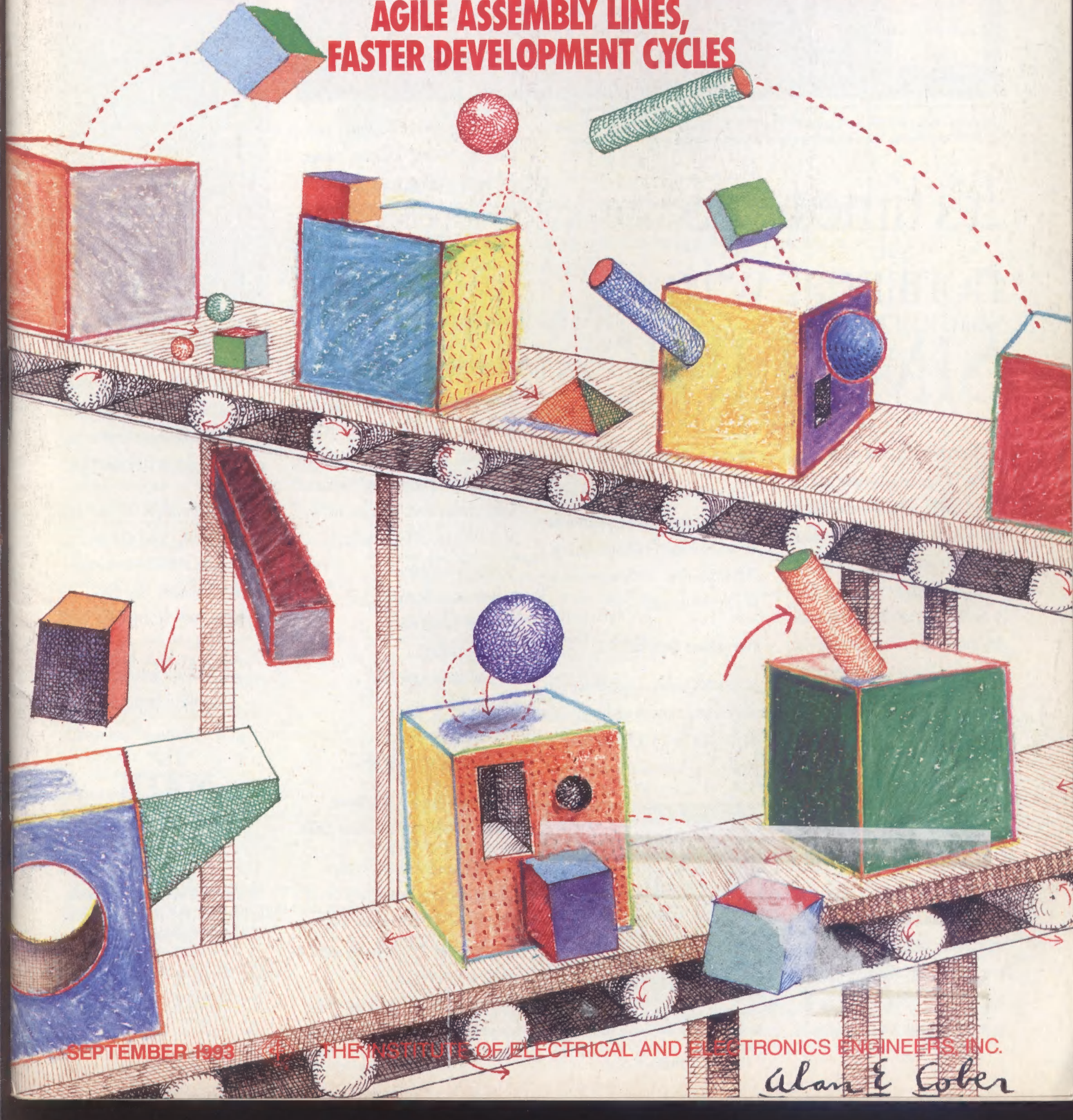

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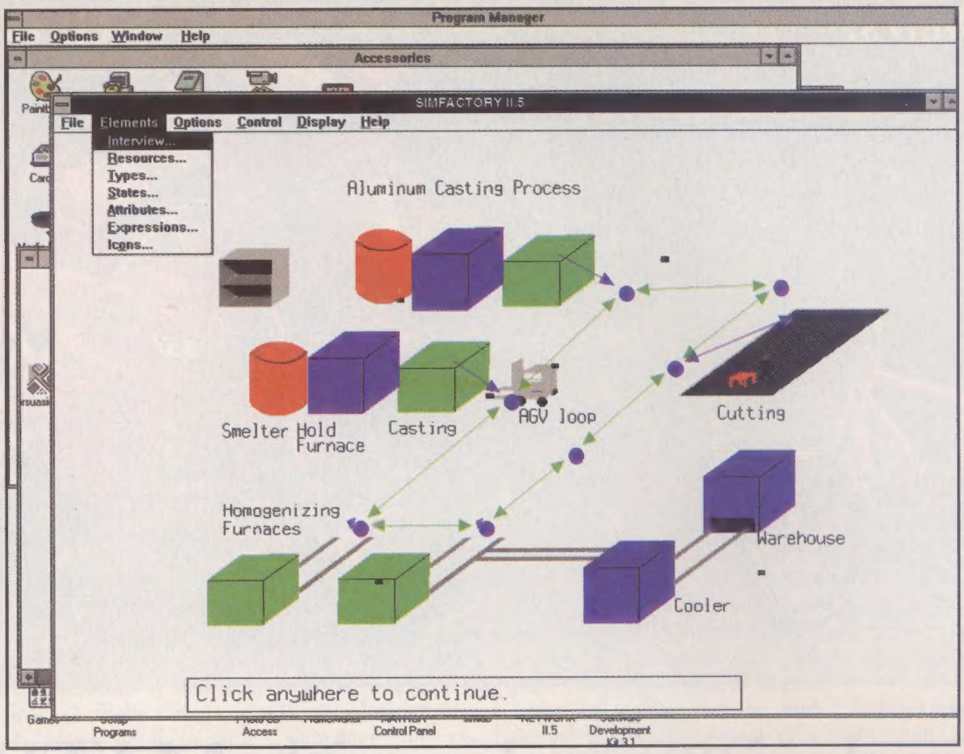

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Newslog

JULY 7. The United Kingdom's **Mercury Communications Ltd.**, a subsidiary of Cable and Wireless PLC, London, said it and **In-Flight Phone International**, Chicago, will launch what they call Europe's first in-flight telephone and facsimile services. The network is expected to have 60 ground stations in place by 1995.

JULY 7. BellSouth Corp., Atlanta, GA, said it had filed a plan with the **Federal Communications Commission,** Washington, DC, to allow outside parties, including rival phone companies, to attach new telecommunications services to BellSouth's advanced computer-based telephone network. The company said the plan would encourage companies to develop computer programs to offer features like voice-activated banking and paging.

JULY 13. Japan's **Sumitomo Chemical Co.** said that a July 4 explosion at its Niihama plant had cut off some 60 percent of the world's supply—or 6000 tons annually—of high-grade epoxy resins, used to package computer chips. The blast, now under investigation, caused semiconductor manufacturers worldwide to scramble to find alternative sources of supply for the resins, and prices for memory chips doubled within a week.

JULY 14. Nokia Corp., the Finnish telecommunications and electronics group, said it would team up with Japan's **Mitsui & Co.** to market digital mobile phones in Japan. Nokia, the world's largest cellular phone maker, will be the first European firm to enter the Japanese market, now dominated by Japanese firms and Motorola Inc., Schaumburg, IL.

JULY 15. Fujitsu Ltd., Japan's largest computer company, said it will shed 6000 employees to reduce its staff to 50 000 by March 1995. The cuts will be made through attrition or by moving employees to affiliates and other companies.

JULY 19. General Electric Co., Fairfield, CT, said that its Industrial and Power Systems unit had signed a US $1.2 billion contract to build a 2800-MW combined-cycle power station for the **Tokyo Electric Power Co.** GE said the plant, in Yokohama, will be the world's largest power station.

JULY 22. Microsoft Corp., Redmond, WA, said the **U.S. Federal Trade Commission** had split 2–2 on whether to issue it with an administrative antitrust complaint on the grounds that the company unfairly uses its dominant power against competitors. The tie vote, after a 37-month investigation, means the company may continue operating as it has. Just days later, the U.S. Justice Department expressed interest in reviewing the case.

JULY 23. Deutsche Telekom, the German state-owned telecommunications monopoly, and **Intertelekom**, the Russian state-owned long-distance telephone operator, said they had agreed to cooperate on a US $1 billion project to modernize Russia's telecommunications infrastructure.

JULY 27. IBM Corp. chairman Louis V. Gerstner Jr. announced a US $8.9 billion program to cut the company's costs sharply, trimming the payroll by 35 000 more people next year and closing several factories. He said the employees to be cut would come from operations outside the United States

JULY 28. The **U.S. Department of Energy** said that **Martin Marietta Corp.,** Bethesda, MD, had won a five-year, US $9 billion government contract to operate the **Sandia National Laboratories,** with operations in New Mexico, Nevada, California, and Hawaii.

JULY 29. MCI Communications Corp., Washington, DC, said it had formed a consortium of over 150 companies that would offer personal communications services, allowing users to receive voice, data, and paging information anywhere in the United States with just a single phone number. MCI said the consortium includes cable, telephone, cellular, and publishing concerns.

JULY 30. The **National Aeronautics and Space Administration** at the Johnson Space Center in Houston, TX, said that unusually heavy debris from a passing comet had forced the postponement of a planned flight of the space shuttle Discovery. Officials said it was the first time a U.S. manned mission into orbit was delayed by a threat from heavenly bodies.

AUG 2. Motorola Inc., Schaumburg, IL, said it had completed its US $800 million first round of financing for a project to launch 66 telecommunications satellites to create the world's first global mobile telephone service. The network, called Iridium, becomes the first of several rival proposals to move beyond the drawing board.

AUG 2. Researchers from the chemical research institute of Japan's **Kyoto University** and **Mie University** said they had developed a new high-temperature material consisting of oxygen, strontium, and copper that will contribute to superconducting research. The material has two forms: one loses all electrical resistance at 70 K; the other, at 100 K. The team used high-pressure synthesis to alter the crystalline structure of the material at 800 °C under a pressure of 60 000 atmospheres.

AUG 2. U.S. intelligence officials said the explosion of a **Titan IV rocket** over the Pacific had destroyed its secret payload, a US $800 million spy system of three solar-powered ocean-surveillance satellites used by the Navy. The explosion was said to be the most costly space accident since the 1986 Challenger shuttle disaster.

AUG 2. Four companies, including Japan's **Marubeni Corp.** and **Nynex Corp.** in the United States, said they had received the green light to build a US $1.2 billion underwater optical-fiber cable between Japan and Europe. Telecommunications firms from 10 countries plan to use the cable once it starts operation, expected in early 1997.

AUG 3. Unisys Corp., Blue Bell, PA, and **Intel Corp.**, Santa Clara, CA, said they would develop a scalable parallel processing system based on open systems technology. The new machines will contain Intel's Pentium microprocessors and make use of Unisys' Unix V.4 operating system and other advanced software.

AUG 3. The **Federal Communications Commission** voted to extend competition in local telephone service by allowing upstart companies to use more of the vast networks operated by the regional Bell companies and other large local carriers. Criticizing the decision was the United States Telephone Association, representing 1100 local carriers, which said the action could lead to higher bills and reduced service, especially for rural customers whose bills are often subsidized by easier-to-serve urban customers.

Preview:

SEP 27-29. The **National Engineering Consortium** will sponsor the **1993 National Communications Forum** at the Hyatt Regency O'Hare Hotel in Chicago. Over 500 industry speakers are to participate in 143 seminars. Call Conference Services at 312-938-3500.

COORDINATOR: Sally Cahur

SEPTEMBER 1993 Volume 30 Number 9

IEEE
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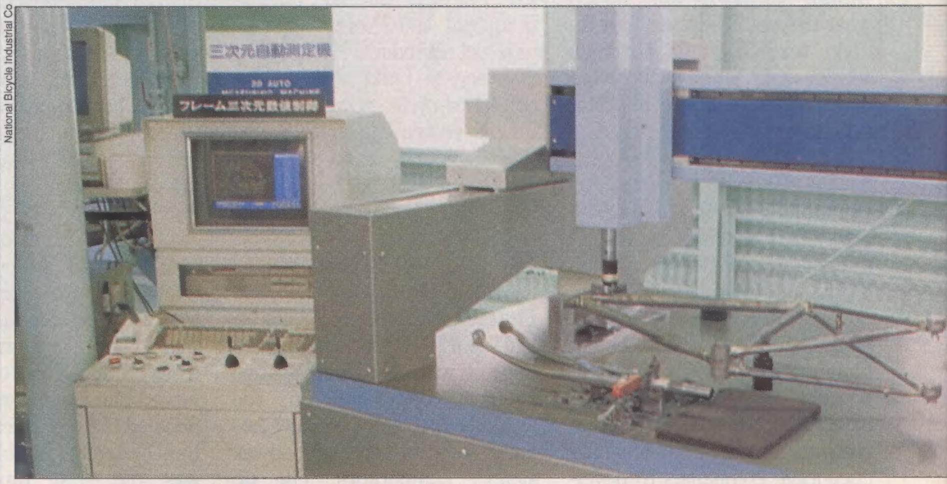
SPECIAL REPORT

National Bicycle Industrial Co.



A customized Panasonic bicycle frame is measured by a computer-controlled system in Osaka.

A Motorola employee in Boynton Beach, FL, checks a robot's work as it agilely assembles custom pagers.

Ned Witrogen

Motorola Inc.

Maintaining quality while catering to a variety of tastes is the philosophy reflected in this line of pagers from Motorola.

Cover: Today's conveyor belts carry every imaginable combination of parts to be assembled, as information technology helps manufacturers cater to customers' tastes and preferences in a timely, efficient manner. See p. 24.
Illustration by Alan E. Cober.

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Forum

Fuzzy logic revisited

It is rather bemusing to read that Daniel McNeill and Paul Freiberger believe that my review of their book was motivated by dissatisfaction with my being left out of it [August, p. 6]. Considering the nature and competence of their work, I can assure them that such omission is a source of considerable relief.

I am also glad that the brief telephone call—now called an interview—made, some time ago, by one of them was so unimpressive that they did not deign it even worthy of cursory acknowledgment (p. 287). In fact, my grasp of matters was apparently so poor that I did not make the cut even under shallow standards that allowed insertion of wild "expert" predictions without any significant efforts to discuss their warrantability. Quite a few of my colleagues who were, on the other hand, mentioned in their book wish now to have been as lucky as I.

I am likewise amused at the notion that I could possibly be disquieted by their assessment of my research work. My technical contributions have been otherwise evaluated, on many occasions, by peers guided by considerably more objective motivations. Examples of such appraisals, contributed by various colleagues, including Lotfi Zadeh, may be found in a recent annotated collection of major papers on fuzzy models for pattern recognition (J.C. Bezdek and S. K. Pal, editors, IEEE Press, 1992).

While the efforts of McNeill and Freiberger to disqualify my review on ethical and professional grounds are hardly worrisome, I cannot be anything but appalled at the ways in which they continue to maul logic to justify their errors. For the sake of brevity, I will confine my comments to some basic points where mistakes such as theirs will earn any logic student considerably less than a passing grade.

McNeill and Freiberger now claim that, in L_3, stating that the negation of "It is possible that *p*" is "It is possible that *not-p*" actually means that the truth-values of both *p* and *not-p* are 1/2. Such a statement is, to put it charitably, a sloppy use of language.

Whether the underlying logic is conventional, modal, or multivalued, and regardless of whether we are denying a sentence in the metalanguage (for example, a truth-value assignment) or whether we are referring to the negation of a well-formed formula, the negation of "It is possible that *p*" is definitely not "It is possible that *not-p*."

Contrary to what McNeill and Freiberger imply, the logic L_3 is, in addition to being a multivalued logic, a modal logic with explicit operators of possibility and necessity introduced by Lukasiewicz to interpret the third value (N. Rescher, *Many-Valued Logic*, McGraw-Hill, 1969, p. 25).

In logic, two formulas *p* and *q* are equivalent when the well-formed formula *p if and only if q* is true for *all*, rather than for *some*, possible assignments of the truth-values to their propositional symbols. Thus, *p* can never be equivalent to *not-p* as the truth of *p* entails the falsehood of *not-p*, and, therefore, that of *p if and only if not-p*. McNeill and Freiberger state, however, that such equivalence is not only possible but, in their example, obvious. Clearly, they confuse the fact that, in L_3, *p if and only if not-p* is true when the truth-value of *p* is 1/2 with its validity, or truth under all interpretations.

The reference to Stoll's book is yet another basic error, mistaking in this case a predicate symbol ("=", denoting the set identity) in an axiomatization of set theory for the logical connective *if and only if* and for the concept of logical equivalence.

It is quite possible to have a multivalued logic where the laws of excluded middle and contradiction—two theorems of classical logic—hold (for example, the continuous logic of Lukasiewicz, often described as a form of fuzzy logic). McNeill and Freiberger confuse the validity of these formulas with availability of more than two values to measure truth.

Finally, it is important to set the factual record straight about some claims made in my review. McNeill and Freiberger deny the inclusion of an epigraph in their book stating the demise of Aristotelian logic. Such an epigraph appears on p. 45. They also deny belittling Aristotle's biographers. Yet they compare (p. 51) the credibility of Diogenes Laertius with that of P.T. Barnum. Their discussion clearly shows, however, that they know as much about the former as they do about Aristotle.

Enrique H. Ruspini
Menlo Park, CA

The authors respond:

Our letter proved that in his review, Enrique Ruspini falsely claimed credit for introducing fuzzy logic to pattern recognition [August, p. 6]. He may find this revelation "hardly worrisome," but it gives an idea of his credibility.

We stand by our letter. Ruspini should never have reviewed our book *Fuzzy Logic* since we interviewed him and omitted him from it. He tries to deny malice, but malice pervades the denial itself. He also has made several mistakes.

For instance, Ruspini claims we think Aristotelian logic is dead. Now, only an ignoramus could think it dead, so the charge is serious and a fair observer would make sure the evidence supports it. But Ruspini relies solely on the epigraph on page 45 of our book: "What makes society turn is science, and the language of science is math, and the structure of math is logic, and the bedrock of logic is Aristotle, and that's what goes out with fuzzy."

If the last clause had read "that's what *went out* with fuzzy," Ruspini might have some evidence. It doesn't, but he makes his accusation anyway.

Likewise, Ruspini says we belittle "Aristotle's biographers"—a whole field of scholarship. In fact, we criticize only one biographer: Diogenes Laertius.

Ruspini originally said we treated Aristotle's "biographers" as flacks. But Diogenes Laertius calls Aristotle bald, thin-legged, small-eyed, lisping, and fond of opulent garb. These are not the words of a flack, and we stand up for Aristotle.

Now Ruspini says we deny criticizing the "biographers" at all. But of course we do criticize Diogenes Laertius. We call him unreliable. Historian Richard Hope says Diogenes Laertius showed "great industry, but also lack of discrimination, coordination and trustworthiness." Jørgen Mejer adds that this "is the *opinio communis* [common opinion] of modern scholars." [Jørgen Mejer, "Diogenes Laertius and His Hellenistic Background," *Hermes*, v. 40, 1978, 1-108, 1.]

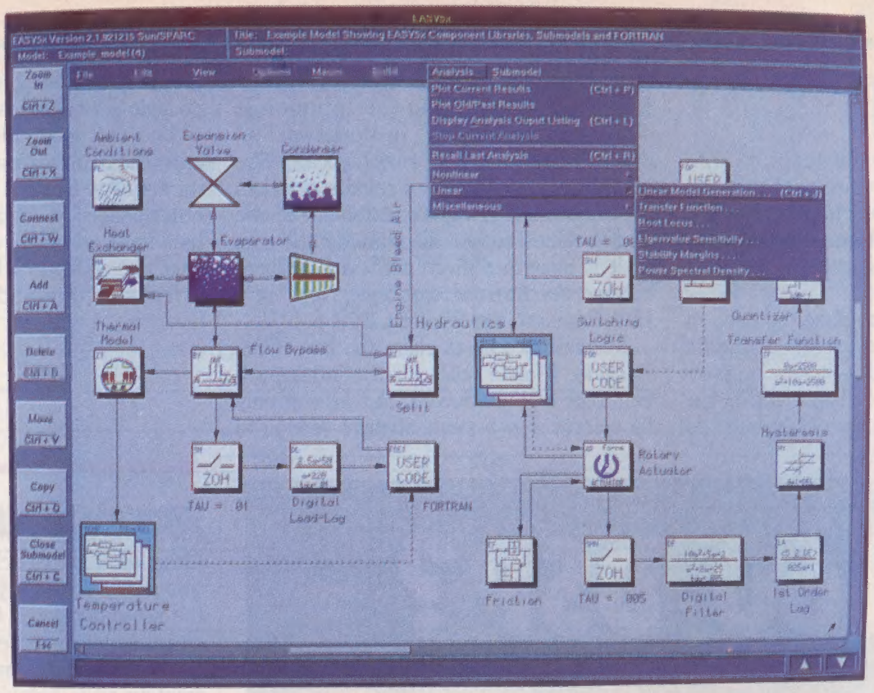
Similarly, we never imply that the three-valued logic ("L3") of Jan Lukasiewicz has no modal aspect, but it is typical of Ruspini, in his eagerness to find fault, to claim we do.

Ruspini's technical criticisms are just as bad. Most deal with L3, and arise because Ruspini has still not bothered to read Lukasiewicz.

For instance, Ruspini adamantly insists that in L3, "*p* can never be equivalent to *not-p*." But Lukasiewicz says, "For *a*=1/2, the sentence *a*=*a* is true." ["On Three-Valued Logic," in L. Borkowski, ed., *Jan Lukasiewicz: Selected Writings*, London, North Holland Publishing Co., 1970, p. 88.] That is, *a*=*not-a*, *p*=*not-p*.

And by "*p-not-p*", Lukasiewicz means "*p* is equivalent to *not-p*." He says, "The expression *p*=*r*, which denotes the relation of equivalence...is read '*p* is equivalent to *r*.' The simplest way of formulating this definition verbally is: 'I assert that, for any *p* and *r*, "*p* is equivalent to *r*" means the same as "*p* implies *r* and *r* implies *p*." ' " ["Two-

(Continued on p. 8)



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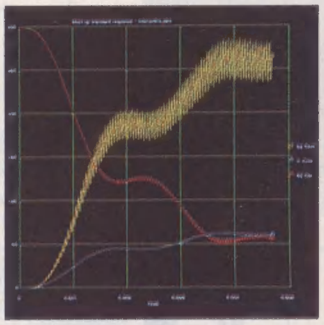

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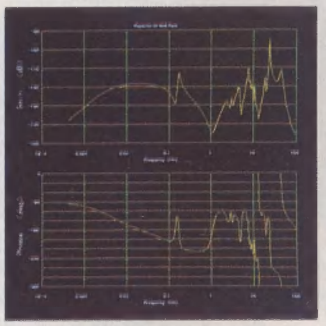

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Circle No. 6

BOEING

Forum

(Continued from p. 6)

Valued Logic," in Borkoweski, p. 98.] Lukasiewicz cites no requirement that this mutual implication hold for all possible truth values. We assume Lukasiewicz would not earn a passing grade in Ruspini's classroom.

Ruspini also says we confuse the Laws of Contradiction and the Excluded Middle with the law of bivalence—"every proposition is either true or false." But Lukasiewicz notes that the law of bivalence is part of the general form of the Law of the Excluded Middle. ["On the Intuitionist Theory of Deduction," in Borkowski, p. 332.] Hence, one text simply says, "The principle of the excluded middle restricts the truth value of a given statement to one of two values. Either the statement is true or it is false in a given context." [William Kilgore, *An Introductory Logic*, New York, Holt, Rinehart, and Winston, 1979, p. 197.]

Ruspini goes on to claim the law of the Excluded Middle holds for the infinite-valued logic of Lukasiewicz. But he can only be referring to a weak, atypical version of the Law, since the general form clearly limits its logic to two values.

The fact that this hostile critic must twist the truth to attack our book attests to its solidity. But his remarks also affect other people. Many great fuzzy logic scientists have endured years of neglect, and it would be a shame if Ruspini's irresponsible criticisms dimmed the spotlight they deserve.

Daniel McNeill
Culver City, CA
Paul Freiberger
San Mateo, CA

Who's a real ham?

Although Robert Lucky's salute to Heathkit was nicely done [July 1992, p. 22], I regret the reasons offered for Heathkit's demise. He missed the mark entirely insofar as amateur radio is concerned. When it comes to amateur radio, today's hams no longer build because existing Federal Communications Commission exams do not demand that amateurs know anything about things electronic. What with examination-by-rote techniques, an applicant can memorize the exact questions and answers that are periodically published beforehand, and quickly "upgrade" to the next license class.

Thus, there's no need to learn by building, or to learn at all for that matter. It really has little to do with the arrival of ultralarge-scale integrated chips, or any other hot technology. A small percentage of hams still build their own gear without being taken in by the latest bells and whistles. The equipment will not usually work as well as the commercial stuff, but that's precisely the point!

The end result of buying versus building, and the rote exams, is predictable: today's typical ham cannot even master fundamentals. In a limited study of 205 hams I did six years ago (multiple-choice exam), only 13 percent could correctly define the term voltage as the work needed to move an electric charge from one point in an electric field to another. Most hams still think voltage is a unit of force or pressure (one young fellow thought it was the "pressure in a pipe").

In short, the educational benefits of learning by reading and doing still outweigh economic considerations (and the commission's desire to ease entry requirements into ham radio). You cannot just throw money at education and technology and hope the problem will be resolved.

Vincent Biancomano
Long Valley, NJ

I would like to respond to John B. Egger's comments on amateur radio [February, p. 65]. I have visited many top technical firms where amateur radio is a common pursuit

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Jeffrey C. Rohrbeck
Devon, PA

IEEE and ARRL. I feel a friendly relationship between the IEEE and ARRL could benefit all.

Michael C. Migliaccio, N3HLM
Philadelphia, PA

software engineers become knowledgeable about, and considerate of, the human component of the system and distance themselves from cosmetic engineers.

I commend Morgan Johns for bringing

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Vincent Biancomano
Long Valley, NJ

I would like to respond to John B. Egger's comments on amateur radio [February, p. 65]. I have visited many top technical firms where amateur radio is a common pursuit

among the technical types. Still, it would not be a bad idea if the IEEE were to start supporting amateur radio, especially with all this talk (depending on whom you talk to) of a shortage of engineers and young people pursuing science careers.

When I entered high school, the first thing I did was to join the radio club (I was WN3KFQ then). The club encouraged me to go on to college, where I was active in IEEE student activities, served as vice president of our college IEEE chapter, and participated in the IEEE Student Prize Paper Contest.

Today, organizations like the American Radio Relay League (ARRL) are instrumental in bringing young people (and adults, too) to science through its publications as well as from the activity of its innovative members who work in schools at all levels and in the community. ARRL publications are used as reference manuals for students and even engineers. Many developments are credited to radio amateurs who experimented, and still do, with cutting-edge ideas.

I am proud to be a member of both the IEEE and ARRL. I feel a friendly relationship between the IEEE and ARRL could benefit all.

Michael C. Migliaccio, N3HLM
Philadelphia, PA

Training software engineers

I read Morgan Johns's Speakout [June, p. 48] with great interest. Although I heartily agree with the author, he failed to raise the question of the competency and training that the "cosmetic engineers" must have to do what they are doing. Proficiency in computer graphics is necessary but is definitely not sufficient.

Most software systems are designed to interface with a human operator. The principles of human-computer interface that help to design the content and format of a display effectively are not taught in computer science departments, though courses may be available as an elective. My experience working with computer science majors indicates they do not understand what constitutes a good interface design. Since computer science majors do graphics design, they should be trained to do it right.

Cosmetic engineers do a double disservice to their customers. Not only do they produce vacuous systems, but they also provide interfaces that may be colorful and snazzy but unsatisfactory. Let us hope that software engineers become knowledgeable about, and considerate of, the human component of the system and distance themselves from cosmetic engineers.

I commend Morgan Johns for bringing this issue to the community. We can make changes only when there is an awareness that change is needed.

Morton L. Metersky
Warminster, PA

I take issue with Morgan Johns's characterizations of those who worry about "icons" and "scrolling" and "graphical mouse-driven environments." Such issues are not strictly superficial and cosmetic in and of themselves and are not a warning sign of engineering incompetence. Incompetence existed long before there were "professional-looking" ways of generating output.

Don't devalue the engineering skills required to create attractive and functional displays. They may actually involve a great deal of time and thought. A good and easy-to-use program is indeed a rare thing.

Jeffrey C. Rohrbeck
Devon, PA

Readers are invited to comment in this department on material previously published in *IEEE Spectrum;* on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversal issues. Contacts: Forum, *IEEE Spectrum,* 345 E. 47th St., New York, N.Y. 10017, U.S.A.; fax, 212-705-7453.

Calendar

Meetings, Conferences, and Conventions

SEPTEMBER

Sixth International Conference on Transmission and Distribution Construction and Live-Line Maintenance (PE); Sept. 12–17; Riviera Hotel and Casino, Las Vegas, NV; Ed Cromer, Nevada Power, MS90A, Box 230, Las Vegas, NV 89151; 702-657-4001; fax, 702-657-4036.

Fourth International Conference on Holographic Systems, Components and Applications (UKRI Section); Sept. 13–15; University of Neuchatel, Neuchatel, Switzerland; Louise Bousfield, IEE Conference Services, Savoy Place, London, WC2R OBL, United Kingdom; (44+71) 344 5467; fax, (44+71) 497 3633.

Magnetic Recording Conference (MAG); Sept. 13–15; University of Minneapolis, MN; Mardi Geredes, IIST, Santa Clara University, Santa Clara, CA 95053; 408-554-6853; fax, 408-554-5474.

Petroleum and Chemical Industry Technical Conference—PCIC '93 (IA, St. Louis, C); Sept. 13–15; Clarion Hotel, St. Louis, MO; Harold B. Dygert, Clark, Richardson & Biskup, 655 Craig Rd., Suite 240, St. Louis, MO 63141; 314-997-1515; fax, 314-997-6117.

International Conference on Control and Applications (CS); Sept. 13–16; Le Meridien Vancouver Hotel, Vancouver, BC, Canada; Guy Dumont, Pulp and Paper Center–UBC, 2385 E. Mall, Vancouver, BC V6P 1Z4, Canada; 604-822-8564; fax, 604-822-8563.

Software Engineering Standards Symposium (C); Sept. 13–17; Hospitality Inn, Brighton, United Kingdom; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Canadian Conference on Electrical and Computer Engineering (Vancouver Section); Sept. 14–17; Hyatt Regency Hotel, Vancouver, BC, Canada; Alan Winter, Chief Operating Officer, MPR Teltech Ltd., 8999 Nelson Way, Burnaby, BC V5A 4B5, Canada; 604-293-5704; fax, 604-293-5300.

Virtual Reality Annual International Symposium (NN); Sept. 18–23; Sheraton Hotel, Seattle, WA; Thomas Caudell, Boeing Computer Services, Boeing Building 33-07, MS 7L-22, 2760 160 Ave., S.E., Bellevue, WA 98008; 206-865-3763.

International Symposium on Semiconductor Manufacturing (ED); Sept. 20–21; Austin Marriott Hotel at the Capital, Austin, TX; Steven Leeke, Texas Instruments Inc., MS 457, Box 655012, Dallas, TX 75265; 214-995-2249; fax, 214-995-1724.

Autotestcon '93 (AES et al.); Sept. 20–23; San Antonio Convention Center, TX; Robert E. Noble, 2500 Fallbrook, San Antonio, TX 78232; 512-491-0311.

Eighth Knowledge-Based Software Engineering Conference (C); Sept. 20–23; Midland Hotel, Chicago; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

15th International Congress on Instrumentation in Aerospace Simulation Facilities—ICIASF '93 (AES); Sept. 20–23; Institute at Saint-Louis, Saint-Louis Cedex, France; Hans J. Pfeifer, French-German Research Institute (ISL), 5 rue de l'Industrie, B.P. 34, F68301 Saint Louis Cedex, France; (33+89) 69 51 60; fax, (33+89) 69 51 62.

Second Network Management and Control Workshop (C); Sept. 21–23; Westchester Marriott Hotel, Tarrytown, NY; Judy Keller, IEEE Communications Society, 345 East 47th St., New York, NY 10017; 212-705-7365; fax, 212-705-7865.

43rd Annual IEEE Broadcast Symposium (BT); Sept. 22–23; Hotel Washington, Washington, DC; Edmund Williams, PBS, Engineering Department, 1320 Braddock Place, Alexandria, VA 22314; 703-739-5172.

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 80055; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7305.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

ATM SWITCHES ENTER COMMERCIAL USE.

WilTel, a leading interexchange carrier in the U.S., announced that it will deploy at least eight ATM switches in its nationwide fiber optic network, offering DS-3 (45Mbps) ATM service to its customers by the end of the year. The move underscores a revolutionary shift to Asynchronous Transfer Mode (ATM) cell switching by telecommunications carriers determined to increase the efficiency of data and video transmission.

NEC is supplying the NEAX61E* ATM Service Nodes for the WilTel deployment. This multi-service platform supports frame relay, SMDS and ATM multimedia services on a common ATM switching fabric. The NEAX61E ATM Service Node provides interfaces for frame relay at DS-1(1.5Mbps) rate; SMDS at DS-1 and DS-3; and ATM at DS-1 and DS-3 rates. ATM at OC-3 (155Mbps) rate will be supported soon. NEC plans to develop interfaces supporting E1 and E3 for European markets.

The NEAX61E ATM Service Node offers important advantages to telephone companies and customers alike. Local exchange companies benefit from the improved service capabilities and reduced costs provided by a multi-service platform. End-user advantages include fast access to new services and flexible bandwidth-on-demand facilities.

*US version

NUMBER 151

AFFORDABLE PORTABLE PHONE EXTENDS TALK.

NEC has introduced the "portable phone for everyone". Inexpensive, yet equipped with all the essential features found on high-end models, P100 series portable cellular phones let you talk longer and go longer before recharging batteries.

The standard battery provides 100 minutes of talk-time or 20 hours of standby. The optional high-capacity battery gives you three hours of talk-time or 34 hours of standby.

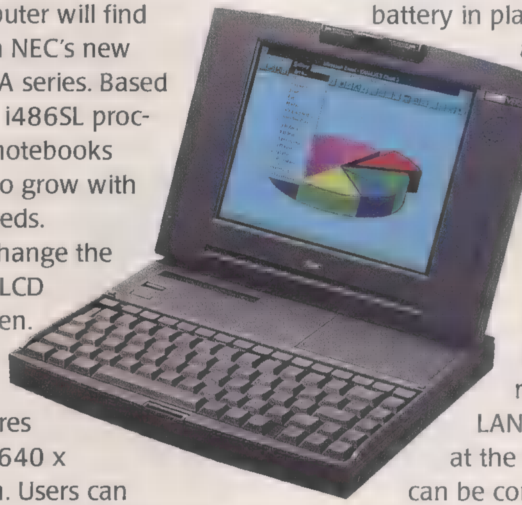
Portable phones in the P100 series feature excellent reception and easy operation. They offer a large LCD which can display up to 16 characters or 32 digits. Illuminated keys are comfortably spaced and protrude slightly for easier dialing. The concave earpiece and noise-cancelling microphone improve speech clarity.

You can convert the P100 series portable phone into a full-featured car phone with a variety of optional car kits. They range from a Cigarette Lighter Adaptor to a simple Hands-Free Kit.

VERSATILITY IN NOTEBOOK COMPUTING.

Mobile professionals looking for versatility in a notebook computer will find the ultimate in NEC's new UltraLite VERSA series. Based on a powerful i486SL processor, VERSA notebooks are designed to grow with each user's needs.

Users can change the monochrome LCD to a color screen. The 9.45" active-matrix TFT LCD features 256 colors at 640 x 480 resolution. Users can expand system memory from 4MB to 20MB and hard disk capacity from 80MB to 180MB or larger. All these changes can be made without turning a screw or disconnecting a wire.



UltraLite VERSA notebooks save power with 3.3V technology and advanced power management. Users can even double battery life by installing an optional second battery in place of the removable floppy disk drive.

VERSA notebooks have two type II PCMCIA slots or one type III PCMCIA slot that accommodates data/fax modem or LAN cards. Back at the office, VERSA can be converted to a full-featured desktop PC via an optional Docking Station.

4M VIDEO RAM FEATURES 60ns SPEED.

Superior graphics performance is crucial to success in the highly competitive market for workstations and high-end PCs. And superior video RAMs are the key to designing great graphics.

NEC's new 4-Megabit video RAMs use 0.5μ CMOS technology to integrate a 256K x 16 RAM and a 512 x 16 SAM. Access speeds to both RAM and SAM are exceptionally fast — 60ns and 15ns, respectively.

Our 4M video RAMs come in two types: fast page mode and hyper page mode. The hyper page type runs at speeds up to 33MHz clock.

Convenient functions for the RAM port include Block Write, Flash Write, Byte Write Control, Write Per Bit and Old Mask.

The SAM port permits operation at speeds up to 50MHz. It features Split Read/Write Transfer and Binary Boundary Jump.

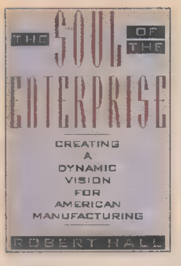
NEC

Books

The vision thing in manufacturing

John E. Ettlie

The Soul of the Enterprise: Creating a Dynamic Vision for American Manufacturing.
Hall, Robert, Harper Business (a division of HarperCollins), New York, 1993, 368 pp., $27.50



The outcry against the post-industrial view of modern society swelled to a crescendo during the 1980s. Now, another strong voice has been added to this small but growing chorus of disapproval. Welcome to the new decade.

In this ambitious book, Robert Hall undertakes nothing less than ■ diagnosis of current ills and ■ prescription for solving the chronic problems confronting manufacturing management. In the process, he defines a new vision of organized enterprise, big and small, which seeks to shift its emphasis from preoccupation with growth to an unflinching focus on the quality of life.

Hall, director of new programs at the Association for Manufacturing Excellence and a professor at the Indianapolis campus of Indiana University, builds on several of his strengths in this latest book. His earlier *Zero Inventories* and his central role in promoting manufacturing excellence through collaboration with manufacturers are well-integrated into the new book's chapters on quality, time compression, and waste elimination. Refreshing introductions to environmental issues in manufacturing (so-called "ecofactory" issues) are welcome additions to the growing library of popular books on manufacturing.

Hall's book does a good job of describing open-systems manufacturing and the learning organization. Here the reader will find all the current buzzwords, including agile manufacturing, virtual manufacturing, and, of course, lean manufacturing. The book's strengths are the chapters detailing these approaches, their underpinnings, and their assumptions. However, it wavers in the chapters on human-resource planning and R&D management, both central concerns for the modern enterprise.

Perhaps, though, a single treatment of the big picture, the "vision thing" as it were, should not become mired in such details. Other, more focused efforts have shown that the introduction of new products is most commonly delayed by incorrect choice of technologies for the product and by top management's intervention in the process.

The dizzying pace of change in manufacturing has left the book a little out of date. This is not the author's fault; any book on this subject these days has to be somewhat dated when it appears. For example, Toyota is by now becoming known for its product design and development methods, as well as for the production system that earns the company acclaim in this and previous works.

The material on the environment and the ecofactory would have to be rewritten daily to be kept fresh. The IEEE has taken ■ leadership role in this area with its conferences on design for the environment. Pollution prevention, it turns out, fits well with the total-quality-management and waste-elimination philosophies that are the foundation of the vision thing. This story and many others will probably be told by future writers, inspired no doubt by this book. Manufacturing, Hall demonstrates, is not just engineering.

In many respects Hall is to be commended for keenly recognizing as many of the timeless fundamentals as he has. These will be well received by those who face the challenge of continuous improvement in manufacturing and are not besotted with the numbers kept to see who is currently in favor on Wall Street. Chapter 7, on benchmarking the open system, is an example of an enduring theme. Good firms have always benchmarked, even without a buzzword for it, and they always will. Benchmarking is being formalized now, but what counts is the principle behind it: you cannot improve unless you know where you stand.

In this regard, Hall may have dealt too harshly with Taylorism and Fordism. Early in this century, Frederick W. Taylor was one of the first to advocate rest periods, and his ideals (as opposed to his ideas) actually mesh very well with lean manufacturing. I have seen them in practice at the joint-venture assembly line in Flat Rock, MI, where the Ford Probe is manufactured. Ford Co.'s Rouge plant has been criticized by most writers and, in retrospect, the criticism is largely deserved. But the facility was, after all, the first example of integrated manufacturing, and we still have much to learn from it.

The same is true of the historical example in the beginning of the book, concerning Ford's Willow Run plant, which produced B-24 bombers during World War II. Yes, the plant had so many productivity problems that it was nicknamed "Will It Run." It was also the first time what is now called redesign-for-assembly was practiced in the aerospace industry. Flyers and mechanics in the field and in various theaters of operation preferred the Willow Run B-24s because they were easier to fix. Interchangeable parts worked.

The point is, there is a strong heritage of manufacturing excellence in the United States. This book helps refocus attention on quality manufacturing, not as ■ *cause célèbre,* but as a fundamental requirement in any modern, sustainable society. In this regard, anyone can benefit by reading this book. It sustains Hall's reputation as ■ manufacturing standard-bearer.

John E. Ettlie (M) is director of manufacturing management research and associate professor of operations management at the University of Michigan in Ann Arbor. He has written more than 50 professional articles and three books, and has presented over 100 professional papers at conferences on the role of technology in manufacturing.

The future of security

M. Granger Morgan

The Highest Stakes: The Economic Foundations of the Next Security System.
A BRIE project with chapters contributed by Wayne Sandholtz, Michael Borrus, John Zysman, Ken Conca, Jay Stowasky, Steven Vogel, and Steven Weber. Oxford University Press, 1992, 262 pp., $29.95

This is ■ well-written and well-integrated collection of chapters by seven members of the Berkeley Round Table on the International Economy (BRIE) at the University of California. The core of the book is Chapter 6, by Steven Weber and John Zysman, which lays out three possible scenarios for future relations between North America, Japan, and Europe.

The most attractive involves "managed multilateralism...an extension of the postwar American system into a new era in which power is more evenly distributed." The second, "less likely" alternative, of "defensive protectionism," involves a division of the world into "three largely autonomous trading regions with relatively low levels of interdependence." The third possi-

bility, which the authors view as disturbingly possible, is "mercantilistic regionalism," in which "the drive for autarky is fueled not by welfare concerns but by worries about relative position and competing state power."

Little explanation is given for the selection of these three scenarios and the exclusion of all others. The direct use of force among the three blocks is ruled out because it is "restrained by norms, by the intense destructive capabilities of modern armies, and ultimately by the existential deterrent that nuclear weapons provide." Yet within these restraints, the authors see the potential for a great deal of tension and counterproductive conflict if the international order is not well-managed over the next few decades.

The book never systematically explores the other possible threats to international security that may emerge, or how these threats might influence relations between the three economic blocks. The Middle East and the disintegrating Commonwealth of Independent States (CIS) receive only cursory treatment. Chapter 5, by Ken Conca, contains a modest case study of Brazil's defense industry, but little political analysis. China and India, two increasingly high-tech nuclear states, which together account for roughly 40 percent of the world's people, also get scant attention.

Like Paul Kennedy's *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000* (Random House, 1987), the authors come close to assuming that the very purpose of great powers is to prepare for conflict. For example, there is frequent discussion of a need for "surge capacity" and the security risks posed by being dependent on other powers for critical defense technologies. But there is never any serious discussion of what kinds of conflicts are likely to require surge capacities.

Japan is dealt with in Chapter 2 (by Steven Vogel) and elsewhere. But again, internal Japanese political problems and the inefficient Japanese public and retail sectors are hardly mentioned. Nor is much said about the serious softening of the Japanese real estate market, whose high prices have until now supplied capital to the banking and insurance industries. Also ignored are such interesting developments as the powerful competitive position of U.S. computer manufacturers, and the fact that proposed Japanese and European standards for high-definition television—developed with large investments by national governments—are now apparently losing out to the more advanced standards developed with private resources by U.S. firms.

Of course, none of these limitations undermines the central argument, namely, that Japan is now an economic superpower that as yet lacks a foreign policy commensurate with its economic strength. Clearly, the form of its future foreign policy will have far-reaching implications. However, a more balanced and nuanced treatment of Japan would have made for a stronger book.

Chapter 3, "Europe's emergence as a global protagonist," by Wayne Sandholtz and Zysman, summarizes Western Europe's post-war economic evolution and the development of the European Community. It asserts that the structural changes caused by Japan's economic rise vis à vis the United States triggered, but did not cause, the 1992 unification process. Alternative possibilities are not advanced, so most readers will find the proposition difficult to evaluate.

Over 25 pages are devoted to fairly mundane commentary on issues of markets, industrial structure, and trade. The emergence of a new role for the Western European union gets half a page. The potential threats posed by tensions in central Europe, the CIS, and southwest Asia collectively receive less than a page. Broader European interests in possible regional conflicts, as well as the role of European arms and high-technology

Books

exports in the militarization of the developing world, are not mentioned at all.

All told, despite much thoughtful and well-written material, the book falls short of fulfilling the title's promise. I am reminded of the fable of the blind men describing an elephant, each focusing on one local set of attributes: the trunk, tail, or a leg. There are a number of books by engineers, physicists, and military strategists about the future of defense policy that ignore issues of politics, economics, and international relations. Some are very good nonetheless.

A much larger set of books, written by specialists in international relations on the future of defense policy, ignore technical and economic considerations. Some of these, too, are very good. Thus, logically, it should not trouble me when a group of political economists writes a book about the future of defense-policy issues focused on trade in the developed world, and ignores many of the substantive details of the future of technology, as well as the specifics of international relations.

Yet I *am* troubled. In recent years, authors have begun to break out of their disciplinary binders when writing about defense policy. Jan Nolan, a social scientist at the Brookings Institution, Washington, D.C., displays considerable technical knowledge in *Trappings of Power: Ballistic Missiles in the Third World* (Brookings, 1991). Also, though their book has other shortcomings, John Alic, Lewis Branscomb, Harvey Brooks, Ashton Carter, and Gerald Epstein adopt a highly interdisciplinary perspective in *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Harvard Business School Press, 1992).

Not only does *The Highest Stakes* fail to achieve a similar interdisciplinary level of treatment, it does not even manage to cite these and several other important recent contributions to the defense-policy literature.

M. Granger Morgan (F) is head of the Department of Engineering and Public Policy at Carnegie Mellon University in Pittsburgh, where he is also a professor of electrical and computer engineering. His research deals principally with problems in technology and public policy. He is a member of IEEE Spectrum's editorial board.

COORDINATOR: Glenn Zorpette

Recent books

PC-Based Voice Processing: How to Design, Build and Program Systems Using Industry-Standard Dialogic Hardware. *Edgar, Bob,* Telecom Library, New York, 1992, 384 pp., $29.95.

Mass Customization: The New Frontier in Business Competition. *Pine, B. Joseph, II,* Harvard Business School Press, Boston, MA, 1993, 321 pp., $29.95.

Teach Yourself C in 21 Days. *Aitken, Peter,* and *Jones, Bradley,* SAMS/Prentice Hall, Carmel, IN, 1992, 786 pp., $24.95.

High Frequency and Pulse Scattering. Eds. *Pierce, Allan D.,* and *Thurston, R.N.,* Academic Press, San Diego, CA, 1992, 329 pp., $99.

Usability. Eds. *Adler, Paul S.,* and *Winograd, Terry A.,* Oxford University Press, New York, 1992, 208 pp., $35.

ALL-IN-1: Managing and Programming in V3.0. *Redmond, Tony,* Digital Press, Burlington, MA, 1993, 576 pp., $52.95.

Physical Acoustics: Ultrasonics of High-T_c and Other Unconventional Superconductors, Vol. XX. Ed. *Levy, Moises,* Academic Press, San Diego, CA, 1992, 465 pp., $99.

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ALL-IN-1: Integrating Applications in V3.0. *Rhoton, John*, Digital Press, Burlington, MA, 1993, 288 pp., $51.95.

Random Access Audio. *Huber, David Miles*, SAMS/Prentice Hall, Carmel, IN, 1992, 316 pp., $26.95.

Guide to the UNIX Desktop. *Negus, Chris*, and *Schumer, Larry*, Unix Press, Summit, NJ, 1992, 711 pp., $34.95.

Windows Programming Powerpack. *Clark, Jeffrey D.*, SAMS/Prentice Hall, Carmel, IN, 1992, 259 pp., $24.95.

C++ Applications Guide. *Smith, James T.*, McGraw-Hill, New York, 1992, 324 pp., $24.95.

Microsoft Guide to Optimizing Windows. *Gookin, Dan*, Microsoft Press, Redmond, WA, 1993, 336 pp., $17.95.

Electro-Optical Displays. Ed. *Karim, Mohammad A.*, Marcel Dekker, New York, 1992, 864 pp., $165.

Microsoft Excel Software Development Kit: Version 4 for Microsoft Windows and the Apple Macintosh. *Microsoft Corp.*, Microsoft Press, Redmond, WA, 1993, 528 pp., $49.95.

Lenk's Digital Handbook: Design and Troubleshooting. *Lenk, John D.*, McGraw-Hill, New York, 1993, 305 pp., $39.95.

Two-Dimensional Digital Filters. *Lu, Wu-Sheng*, and *Antoniov, Andreas*, Marcel Dekker, New York, 1992, 416 pp., $115.

Running Microsoft Access. *Viescas, John L.*, Microsoft Press, Redmond, WA, 1993, 544 pp., $29.95.

Electronic Phase Transitions, Vol. 32. Eds. *Hanke, N.*, and *Kopaev, V.*, Elsevier Science Publishers, New York, 1992, 320 pp., $179.50, $155 (subscription price).

Inside Windows NT. *Custer, Helen*, Microsoft Press, Redmond, WA, 1993, 416 pp., $24.95.

The Elements of C Programming Style. *Ranade, Jay*, and *Nash, Alan*, McGraw-Hill, New York, 1993, 340 pp., $29.95.

Computing for Scientists and Engineers. *Thompson, William J.*, John Wiley & Sons, New York, 1992, 444 pp., $54.95.

Power System Relaying. *Horowitz, Stanley H.*, and *Phadke, Arun G.*, RSP/John Wiley & Sons, New York, 1992, 281 pp., $59.95.

VMS for Alpha: Platforms, Internals and Data Structures, Preliminary Edition, Vol. 2. *Goldenberg, Ruth E.*, and *Saravanan, Saro*, Digital Press, Burlington, MA, 1992, 314 pp., $30.

Portable Power. *Banks, Michael A.*, Brady/Prentice Hall, Carmel, IN, 1992, 289 pp., $29.95.

Digital Avionics Systems: Principles and Practice, 2nd edition. *Spitzer, Cary R.*, McGraw-Hill, New York, 1993, 277 pp., $49.95.

ISDN Explained: Worldwide Network and Applications Technology, 2nd edition. *Griffiths, John M.*, John Wiley & Sons, New York, 1992, 239 pp., $42.95.

The C Graphics Handbook. *Stevens, Roger T.*, Academic Press, San Diego, CA, 1992, 790 pp., $39.95.

Pattern-Recognition Transforms. *Moharir, P.S.*, RSP/John Wiley & Sons, New York, 1992, 272 pp., $95.

(Continued on p. 18HE)

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$$\nabla \times H = J + \epsilon \frac{\partial E}{\partial t} \quad \nabla \times E = -\mu \frac{\partial H}{\partial t} \quad \nabla \cdot E = \frac{\rho}{\epsilon} \quad \nabla \cdot H = 0$$

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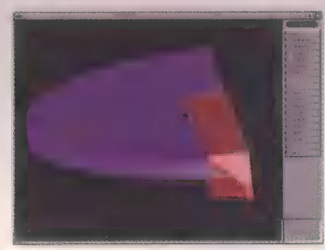

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Recent books

(Continued from p. 18BE)

Antennas for Radar and Communications: A Polarimetric Approach. *Mott, Harold*, John Wiley & Sons, New York, 1992, 521 pp., $69.95.

Corporate Networks: The Strategic Use of Telecommunications. *Valovic, Thomas*, Artech House, Norwood, MA, 1993, 159 pp., $62.

Stochastic Electromagnetic Image Propagation: An Adaptive Compensation. *Manning, Robert M.*, McGraw-Hill, New York, 1993, 229 pp., $49.95.

Organic Coatings: Science and Technology, Vol. I. *Wicks, Zeno W., et al.*, John Wiley & Sons, New York, 1992, 343 pp., $85.

Winning in High-Tech Markets: The Role of General Management. *Morone, Joseph G.*, Harvard Business School Press, Boston, 1993, 304 pp., $29.95.

Prospering in a Global Economy: Linking Trade and Technology Policies. Eds. *Harris, Martha Caldwell*, and *Moore, Gordon E.*, National Academy Press, Washington, DC, 1992, 176 pp., $21.

Introduction to Artificial Neural Systems. *Zurada, Jacek M.*, West Publishing Co., St. Paul, MN, 1992, 785 pp., $51.75.

Dispelling the Manufacturing Myth: American Factories Can Compete in the Global Marketplace. *National Research Council*, National Academy Press, Washington, DC, 1992, 128 pp., $24.95.

Idea Power: Techniques and Resources to Unleash the Creativity in Your Organization. *VanGundy, Arthur B.*, Amacom, New York, 1992, 240 pp., $24.95.

Virtual Reality: Through the New Looking Glass. *Pimentel, Ken*, and *Teixeira, Kevin*, Intel/McGraw-Hill, New York, 1993, 301 pp., $22.95.

Polymers for Lightwave and Integrated Optics: Technology and Applications. Ed. *Hornak, Lawrence A.*, Marcel Dekker, New York, 1992, 768 pp., $150.

Time Management for Teams. *Douglass, Merrill E.*, and *Douglass, Donna N.*, Amacom, New York, 1992, 215 pp., $17.95.

Mazes for the Mind: Computers and the Unexpected. *Pickover, Clifford A.*, St. Martin's Press, New York, 1992, 455 pp., $32.95.

Understanding Database Management Systems: An Insider's Guide to Architectures, Products, and Design. *Mattison, Robert M.*, McGraw-Hill, New York, 1993, 537 pp., $49.95.

Digital Signal Transmission. *Bissell, C.C.*, and *Chapman, D.A.*, Cambridge University Press, New York, 1992, 321 pp., $79.95 (hardcover), $34.95 (paperback).

The Analytical and Numerical Solution of Electric and Magnetic Fields. *Binns, K.J., et al.*, John Wiley & Sons, Somerset, NJ, 1992, 470 pp., $79.95.

Theory and Design of Digital Computer Systems, 2nd edition. *Lewin, Douglas*, and *Noaks, David*, Chapman & Hall, New York, 1992, 494 pp., $40.95.

TCP/IP: Architecture, Protocols, and Implementation. *Feit, Sidnie*, McGraw-Hill, New York, 1993, 466 pp., $44.95.

Acronyms and Abbreviations of Computer Technology and Telecommunications. *Tavaglione, David*, Marcel Dekker, New York, 1993, 304 pp., $45.

Windows for Workgroups Companion. *Borland, Russell*, Microsoft Press, Redmond, WA, 1993, 528 pp., $27.95.

Switch Engineering Handbook. *Mason, John R.*, McGraw-Hill, New York, 1993, 496 pp., $59.95.

Custom VLSI Microelectronics. *Hurst, Stanley L.*, Simon & Schuster, New York, 1992, 466 pp., $48.

Thermodynamics and Gas Dynamics of the Stirling Cycle Machine. *Organ, Allan J.*, Cambridge University Press, New York, 1992, 415 pp., $120.

Technological Forecasting for Decision Making, 3rd edition. *Martino, Joseph P.*, McGraw-Hill, New York, 1993, 462 pp., $64.95.

Modern Radar System Analysis Software and User's Manual, Version 2.0. *Barton, David K.*, and *Barton, William F.*, Artech House, Norwood, MA, 1993, 214 pp., $375.

PEXlib Programming Manual. *Gaskins, Tom*, O'Reilly & Associates, Sebastopol, CA, 1992, 1154 pp., $44.95.

Silicon Mirage: The Art and Science of Virtual Reality. *Aukstakalnis, Steve*, and *Blatner, David*, Peachpit Press, Berkeley, CA, 1992, 300 pp., $15.

Up the University: Re-Creating Higher Education in America. *Solomon, Robert*, and *Solomon, Jon*, Addison-Wesley, New York, 1993, 336 pp., $24.95.


UP

Program notes

Gaining a space dividend

Now software developers can benefit from U. S. space efforts by building applications using low-cost software originally developed for such programs under government funding by the National Aeronautics and Space Administration (NASA) or its contractors. Cosmic—NASA's Software Technology Transfer Center at the University of Georgia in Athens—is a source of information on this software.

Sponsored by NASA and the university, Cosmic publishes a pair of catalogs describing over 1200 programs, most with source code. The programs in the international catalog can be distributed throughout the world, while those in the domestic one can be distributed only in the United States. Cosmic prices programs on a cost-recovery basis: US $100 is a typical price for a PC program, $1000 for a VAX program.

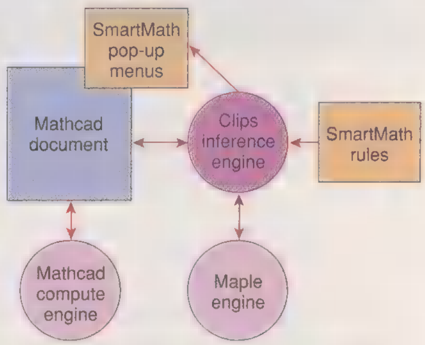
Using the Internet, developers can download the catalog as a DOS-executable hypertext document, with search engine, through anonymous ftp addressed to cossack.cosmic.uga.edu (or 128.192.14.4). Those lacking access to Internet can purchase a printed copy of the catalog or the hypertext version on disk.

Cosmic offers two other tools to developers. One is Cosline, an on-line interactive information service that is accessed through the Internet using telnet (cosline.cosmic.uga.edu or 128.192.14.11) or through a dial-up modem (706-542-7354). The other is an Internet listserver host for electronic conferences—those covering areas of interest to users of certain software packages. *Contact: Richard Saunders or Tom Broom, Cosmic, University of Georgia, 382 E. Broad St., Athens, GA 30602-4272; 706-542-3265; or* **circle 100.**

Employing a NASA math expert

One commercial company already using the U.S. space agency's software is MathSoft Inc., Cambridge, MA. The company has built Clips, an artificial-intelligence inference engine, into SmartMath, an equation-solver enhancement for its Mathcad 4.0 technical calculation software. SmartMath uses Clips to supply an intelligent interface between the user's problem and Mathcad's numeric and symbolic capabilities.

When SmartMath is turned on, Clips



NASA's Clips adds artificial intelligence to MathSoft Inc.'s Mathcad to produce SmartMath, an equation solver enhancement. Rules for selecting appropriate mathematical methods, along with user information on a problem, are evaluated by an inference engine that guides the user to a solution.

evaluates the user's input and offers additional solution paths based on rules in the SmartMath knowledge base. For example, Clips knows the capabilities of Mathcad's Maple symbolic equation solver. So whenever Clips examines an equation block that specifies a numerical solution to an integral equation, it tests the equation to see if Maple can calculate an exact solution.

The default SmartMath knowledge base contains rules for two enhancements to Mathcad. The first set of rules implements live symbolics: SmartMath evaluates all expressions symbolically, using all previous definitions in the document. When an expression is changed, those following it all reflect that change. The second set of rules provides symbolic/numeric optimization of all expressions: SmartMath calls Maple to simplify all expressions before they are turned over to the Mathcad numerical analysis computer engine, a process that reduces the time needed to obtain numerical solutions. *Contact: MathSoft Inc., 201 Broadway, Cambridge, MA 02139-1901; 617-577-1017; or* **circle 101.**

Intel's helping hands

Competition among hardware developers often changes the job market for software developers. Usually, that rivalry results in software developers having to acquire a new skill, such as the ability to exploit a new processor architecture fully. But it may also change the places where they work if a recent trend proves permanent.

To help create its new Pentium microprocessor, Intel Corp., Santa Clara, CA, hired a team of compiler specialists for advice on how choices in processor design impact software development. To test the effect of those design choices, the team created several versions of Pentium-specific optimizing compilers—programs that produced machine code customized for each design option.

The upshot was that Intel realized compiler developers would need quite some time to become intimately familiar with Pentium. This would, in turn, delay introduction of the first Pentium-specific compilers. In all probability, those early compilers would not produce fast-running code, casting doubts on Pentium's performance.

To prevent that from happening, Intel offered key software developers two choices: education or software. Some of them chose to have a member of the compiler team teach the details of Pentium technology to their in-house personnel. Then, well in advance of the availability of Pentium-based PCs, the in-house staff could add Pentium optimization to products.

Other software developers chose instead to license Intel's optimization technology. It has not been offered to the general public, however; Dan Palka, an Intel spokesman, explained that considerable effort was still required to fit the optimizer to a compiler.

Programs compiled with Pentium-specific optimization may give DOS and Windows users reason to pay extra dollars to purchase new PCs. That is good news for Intel since Pentium is more profitable for it than the 80486, which this year became a commodity product with multiple sources. The optimizer may also give the Intel chip an edge in performance over DEC Alpha and Motorola Power microprocessors.

If equipping users with optimizing compilers helps Pentium succeed, other microprocessor developers may decide to copy Intel, opening up new positions for compiler developers at chip makers. Microprocessor design teams would grow much larger with the addition of specialists whose job it was to create software that showcases the processor's unique features.

CONTRIBUTOR: John R. Hines is silicon sensors engineer at Honeywell Inc.'s Micro Switch Division, Richardson, TX.
COORDINATOR: Richard Comerford
CONSULTANT: Bruce Mather, Southwest Research Institute

EV watch

Littelfuse developing fuses for Ford's EV program

As Sherlock Holmes was wont to emphasize, it is often the ostensibly unimportant details that turn out to be the most significant. One such detail that the great detective might appreciate is the work going on at Littelfuse Inc., Des Plaines, IL, to develop power fuses for use in Ford Motor Co.'s electric vehicle program.

Although perhaps lacking in glamour, EV power fuses will be an essential part of any serious commercial EV. Consequently, the fact that Ford and Littelfuse are working on them is evidence that the automobile manufacturing establishment is indeed taking EVs seriously.

The project is far from trivial technologically. After all, an EV propulsion battery will typically have a voltage rating of several hundred volts, and will put out tens of thousands of amperes if shorted. The problem is to distinguish a normal high-current situation from one in which the fuse should blow. Dead shorts are fairly easy to handle. The real challenge, according to Ad Huizenga, who handles the automotive original-equipment market for Littelfuse, is to design a fuse that will not blow during normal hard acceleration, but *will* blow if the battery or drive train appear to face irreversible damage.

That is not a distinction that can easily be reduced to a single current value. In fact, according to chief power fuse engineer Heraclio R. Gomez, it will be the Littelfuse High-Power Test Lab's most challenging project so far.

Pike's Peak record

An electric race car built by Arizona Machine & Fabrication Inc. (Amfab) set a new EV record for the Pike's Peak Hill Climb, covering the traditional 20-km course in 27:37.21 minutes for an average speed of 43.45 km/h. The course runs from Mile Post 7 to the summit of the mountain, starting at an elevation of 2865 meters and finishing at 4301 meters—a climb of 1436 meters. Maximum grade on the twisty course is 10 percent.

The record was set during this year's Chevrolet Pike's Peak Auto Hill Climb, held for the 71st time on July 4. The event is the second-oldest auto race in the United States, having first been run in 1916. (Only the Indianapolis 500 is older.) The Hill Climb is a speed contest in which vehicles run against the clock, one car at a time.

The Amfab car is a tube-frame sand buggy powered by an off-the-shelf General Electric dc motor and a standard controller. It gets its energy from 20 Optima 800 batteries. These are rechargeable, dry, lead-acid batteries of a type associated with conventional automotive applications—not the deep-discharge types associated with EVs. However, as Amfab president Philip C. Terry told *IEEE Spectrum*, "Optima told us they would give us the current we needed for the time we needed, and they did."

Is range really the problem?

In a survey of people's driving habits, conducted to determine what range an EV must have to meet the needs of most drivers, General Motors Corp. found that about 70 percent use their cars to go less than 80 km a day. Since the latest version of the company's EV—the Impact 4—has a city driving range of about 110 km (to 80 percent depth of discharge of its lead-acid battery), GM concludes that using an EV will not affect the driving habits of most commuters.

The survey covered drivers in three U.S. metropolitan areas: Boston, Houston, and Los Angeles. It found that about 80 percent of those surveyed park their vehicles in their own garages or driveways, making them good candidates for home charging.

More on the Impact 4

Speaking of the Impact 4, the car was officially certified as a zero-emissions vehicle by the California Air Resources Board on June 23. GM now plans to build 50 of them, to lend to 1000 potential customers for periods of two to four weeks each. The idea is to educate consumers in what EVs can do and, at the same time, to garner feedback from them.

EVs proceeding apace

An overview article on the status and prospects for EVs is featured in this month's issue of the *Proceedings of the IEEE*. Written by C.C. Chan (F), director of the research center at the University of Hong Kong, the paper compares electric drive and battery systems, and also discusses what EVs are likely to do for air quality in the coming years. Among its conclusions: the world market for EVs is likely to reach 2.5 million vehicles by the year 2001.

On the EV calendar

An October workshop will discuss the technological obstacles to the commercialization and widespread acceptance of electric and hybrid electric vehicles and to develop ways of overcoming those obstacles. Called the Workshop on Advanced Components for Electric and Hybrid Electric Vehicles, it will be held Oct. 27–28 at the Gaithersburg, MD, Hilton Hotel under the auspices of the National Institute of Standards and Technology (NIST).

A secondary purpose is to provide a forum for identifying potentially useful technologies and developing specifications and programs needed for future generations of components. The workshop will include overviews by invited speakers and discussion sessions in five areas: energy conversion systems, energy storage systems, electric propulsion systems, control and instrumentation, and ancillary systems. Registration forms are available. *Contact Lori Phillips of NIST at 301-975-4513.*

In a more or less complementary conference scheduled to run Dec. 1–3, the


AB Volvo

Hybrids like this Volvo Environmental Concept Car (ECC) will be discussed at the NIST workshop, Oct. 27–28 in Gaithersburg, MD. The ECC's range-extending heat engine is a high-speed gas turbine.

Electric Power Research Institute (EPRI) will address EV infrastructure issues—the challenges that electric utilities face in ensuring that EVs can be charged safely and conveniently. Among other things, the conference will present and review the efforts of its various Infrastructure Working Committees in such areas as connectors and charging stations; health and safety; load management, distribution, and power quality; data interfaces; and utility information and customer education.

The conference will be held at the Hyatt Regency Scottsdale at Gainey Ranch in Scottsdale, AZ, and will include opportunities to ride and drive EVs. Registration forms are available. *Contact: Pam Turner, Conference Coordinator, Electric Power Research Institute, Box 10412, Palo Alto, CA 94303-9743; 415-855-2010.*

COORDINATOR: Michael J. Riezenman
CONSULTANTS: James V. Janasik, Electric Power Research Institute; and Victor Wouk, Victor Wouk Associates

Reflections

Chair power

I sat back in my seat, feigning ease, as the chairman of our committee illuminated the first Vugraph of our final report. This chart summarized our conclusions, and since I had never seen it before, I read it with special interest. It was immediately apparent that none of my recommendations had been included.

I glanced at another committee member and shrugged eloquently (I hoped). As far as I could tell, none of his opinions were reflected in the chart, either. He signaled to me with a slight tilt of his head, and as I leaned toward him, he whispered, "Whoever is the last to touch a Vugraph holds the power." Belatedly, I realized that our chairman had finally exercised the power of his position.

During committee meetings, the chairman had seemingly abdicated responsibility. He sat quiet and inert as the rest of us floundered leaderlessly. We would take turns grasping the chalk and trying to organize the rudderless conversation, always with a sidelong glance at our appointed chairman. But as discussion ensued, he remained silent. The only noise from his corner of the table was the clacking of the keys on his laptop computer. What was he writing, we wondered. Was he taking notes? If so, which points was he recording—in what form—and which were being ignored? A feeling of helplessness engulfed us and stifled meaningful exchange. Kafka would have approved, I'm sure.

In the best tradition, the chairperson of a committee lists points as they are raised, so you have some idea of where you stand. This isn't as easy as it sounds. You make some brilliant point, but the chairperson does not write anything down. Then some idiot makes a ridiculous statement that is totally without merit, and the chairperson writes it down as a major conclusion. You try again—louder, of course, for effect, and faster so as to get in more words before his attention wavers. Still his writing hand does not move. As I said, at least you know where you stand.

Thinking like an engineer, I often contemplate analogies between the problems of moderating committee discussion and determining protocols for communication. In a committee meeting there is one common channel—the air—that must be shared among many users. Issues of admission and flow control, contention, buffering, fairness, and efficiency naturally arise. As the number of participants increases beyond about six, the single conversational channel begins to look like the Harbor Freeway in Los Angeles at rush hour. There is no logical way to multiplex the limited channel resources fairly among the potential users.

The traditional communications engineering approach is to have a central authority responsible for scheduling channel usage. Some human leaders use the same strategy, often hiding pompously behind *Robert's Rules of Order*. You make reservations to talk via a separate control channel; that is, you raise your hand and the chairman puts you on a list to speak. "Let's see," he says, "I have Al, Pat, John, Karen, Bill, and George in that order."

In my humble opinion (IMHO—the most common expression on computer nets), this is a terrible way to run a meeting. The next speaker, Al, makes a point that you know is wrong. You raise your hand and the chairman schedules you to speak at the end of the queue after George. But by the time George has gotten the floor and made his point, nobody cares anymore about your rebuttal of Al's long-forgotten point. Since, however, you now have the floor, you use the time to make some gratuitous comment about something else. Everyone seems to be speaking in non sequiturs, and the whole system seems only to be churning pointlessly.

At the other extreme are the laissez faire anarchies codified in the protocols for local-area networks like Ethernet. No chairman is required; if you want to speak, you wait for a pause in the conversation and simply leap in. If someone else also leaps in, you both stop speaking for random intervals. This works fine for small groups, but gets tricky for larger ones, where the pauses in conversation begin to be measured in microseconds. All your senses need to be tuned to detecting a hesitation in the torrent of talk.

With a still larger meeting, this protocol tends to become unstable. Now there are no discernible pauses in conversation. Realizing that you will never capture the floor by waiting, you adopt the strategy of interrupting the current speaker whenever you anticipate a pause. (Local-area network electronics should be so smart!) The aim is to be the first person to interrupt without being outright discourteous. In some larger groups the constraint owed to courtesy is removed.

Sometimes the chairperson will adopt a token-passing protocol. "Let me go around the table and get everyone's opinion," he says. While this approach ensures a certain level of fairness, it also decreases efficiency by forcing a lot of people to talk who have nothing to say. The fairness is not perfect, either, since if you sit at the wrong end of the table, all your points will be used before it is your turn. Naturally, you will speak anyway, dithering somewhere between repetition and irrelevance.

These are all mechanical protocols, requiring no intelligent control by the chairman. Greater efficiency requires active, intelligent intervention. "The chair rules that your argument has no merit, Al, and that further discussion in this direction will not be necessary," he might say. "Now who else would like to talk?" This seems like deft chairmanship unless, of course, your name is Al.

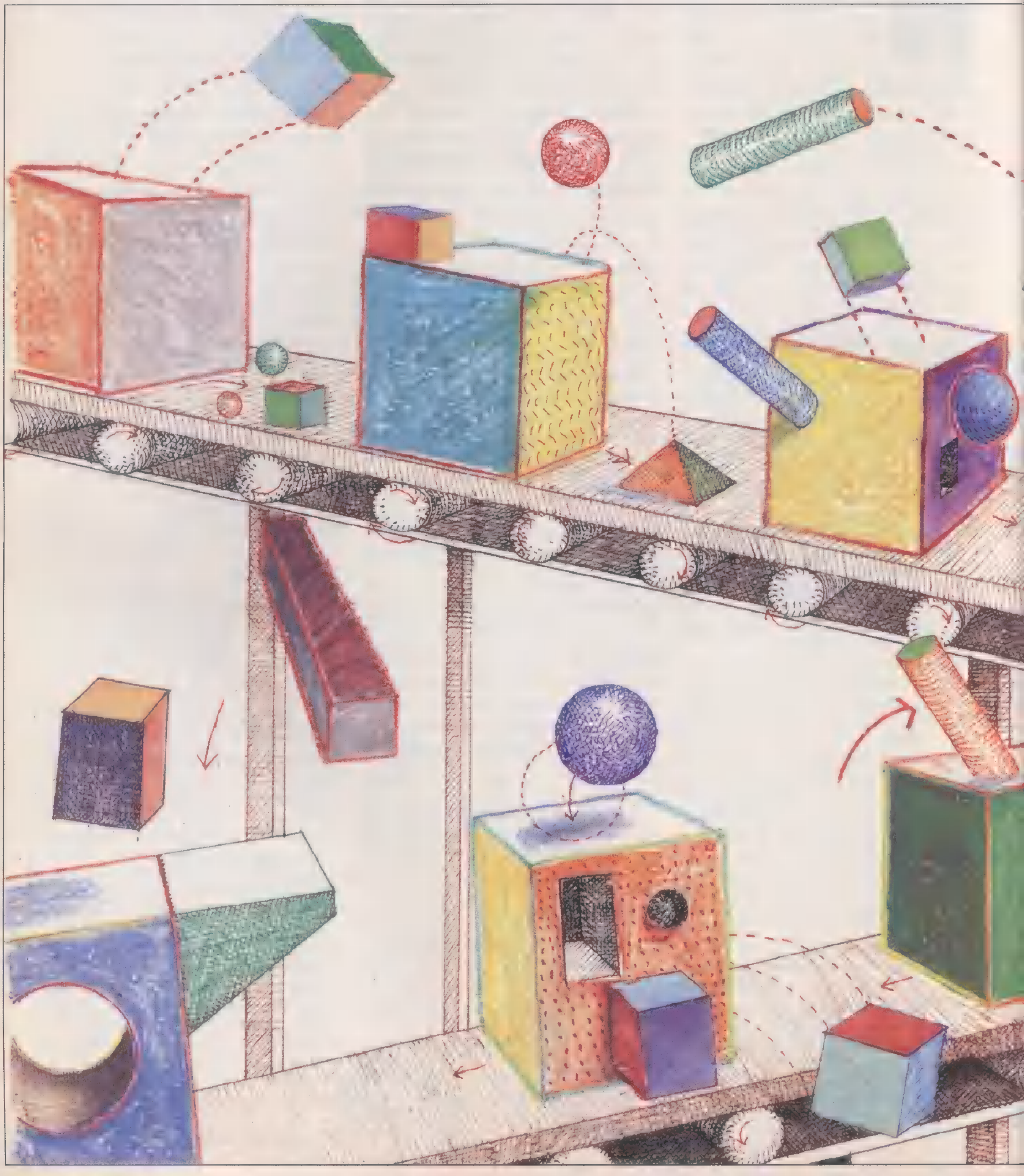
Electronic systems could be improved greatly by similar strategies. You would be typing away at your terminal, and suddenly the screen would stop registering your keystrokes. A little message would say, "Further information of this sort will not be accepted by the network—please use better material in the future."

Most known communications protocols have been shown to be unfair in some way. It is, alas, the same with human leaders. I think that the problem of optimizing the use of conversation time is basically unsolvable, and that we are talking about choosing among suboptimal, even disagreeable, alternatives. There are flavors of chairmanship for every taste. Some are too dictatorial for me; some are too passive. And what pleases me may not be to your taste at all. You may, for example, prefer a chairman who types quietly in a corner, summarizing conclusions that he has crafted from his own imagination. However, I doubt it.

Robert W. Lucky

MANUFACTURING À LA CARTE

AGILE ASSEMBLY LINES, FASTER DEVELOPMENT CYCLES



Alan E. Cober

The goal of manufacturing at companies throughout the world is processing orders sooner, faster, and without pausing for retooling, even for lots of one. The buzzwords are "lean," to describe efficient, unwasteful, less costly manufacturing; "agile," said of a manufacturing system's speed in reconfiguring itself to meet changing demands; and "flexible," meaning the system's ability to adjust to customers' preferences.

Companies are vowing to put customer satisfaction high, or even first, on their list of priorities. And giving the buyer the freedom to pick a product with the color, size, shape, and other features dearest to his or her heart is, in effect, manufacturing *à la carte*.

Behind this evolution are massive economic pressures for global competitiveness. To surmount them, reduced product costs must go hand in hand with superior quality, evidenced by fewer defects and a reduced failure rate. Electrotechnology and information technology are major contributors to these developments. Computers, networking, communications, and control systems, moreover, not only enable changes but are influenced by them as well. This special issue captures these trends with case studies and feature articles that focus on eight themes—flexibility, quality, efficiency, the environment, the economy, government and industry support, education, and the future.

FLEXIBILITY. In Japan, a flexible manufacturing system at the National Bicycle Industrial Co. makes personalized Panasonic bikes by means of computer-controlled assembly robots working alongside ■ skilled master craftsman. More than 11 million variations are possible and, thanks to just-in-time processing, the unique made-to-order machines are delivered within two weeks [p. 32].

Extreme precision and a contamination-free environment are indispensable to the flexible, fully automated system that assembles inertial instruments in The Charles Stark Draper Laboratory Inc., Cambridge, MA. The gas bearings in these instruments have a clearance of ■ mere 1.5 micrometers—the width of ■ semiconductor feature—and would be destroyed by particles in the breath of assembly technicians, or by the gentlest human touch. Remotely operated wrists developed expressly for this assembly task can maintain a contact force of at most 0.1 newton [p. 39].

At Motorola Inc.'s Paging Products Division, Boynton Beach, FL, machines assemble pagers to order in a lot size of one without extending the factory's cycle time [p. 29].

A technique that adds to manufacturing flexibility while shortening the design and manufacturing cycle is rapid prototyping. Here stereolithography, the most popular approach, uses ■ laser to cure liquid polymer, layer by layer, in cross sections that stack up into the desired product shape. This technique has slashed the time to market of electrical and communications products [p. 28].

Gadi Kaplan Issue Editor

QUALITY. These days many companies are zeroing in even harder on product quality, trying to quantify it in terms of how far it meets customer expectations. Experts at Motorola Inc., who pioneered the world-renowned six-sigma technique, define quality in terms of total defects per unit; it is measured throughout production, including the manufacturing phase [p. 43].

EFFICIENCY. The realization is growing that designing some products from the start for automatic assembly saves time during the critical production phase. Design-for-manufacturing software helps circuit-board manufacturers, for example, assess how densely components may be packed on a board without impeding assembly [p. 51].

When looking to improve manufacturing efficiency, it helps to recall that it is a phase—part of a more elaborate process that starts with the placement of an order. This reminder is particularly relevant to such large, varied product lines as medium-voltage switchgear for power-distribution substations. Engineers with ABB Medium Voltage Switchgear based in Baden, Switzerland, along with ABB Production Technology, redesigned their product line and the ordering process, with emphasis on customer requirements. The customer specifies what is needed in the switchgear cubicle and a salesperson's workstation automatically generates on its screen the switchgear configuration, based on standard products and available options and variations. The ordering system reduced the time for placing the complex order from 140 to 8 hours, a substantial saving in time and manpower [p. 57].

ENVIRONMENT. Not only the customer but also the environment demands satisfaction. Environmental considerations are counting for more and more in the manufacturing equation. Engineers at IBM Corp. have designed a PS/2 computer that uses parts that are made primarily of one polymer and simply snap together, to ease later disassembly and recycling [p. 63].

ECONOMY. A question naturally poses itself: how should the available manufacturing resources—technology, workforce, and management—be used for the best results? There is no easy answer, and the competitive manufacturer will be forced to find its own right mix [p. 68].

GOVERNMENT SUPPORT. Help from above is invaluable to the smaller manufacturer. In Japan, 170 Kohsetsushi—government sponsored technology centers—provide affordable technical guidance and

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consulting, testing and analysis, training and other services to companies with 300 or fewer workers [p. 70]. In the United States, the Congress is expected to earmark $350 million this year for this purpose, and there are also individual state-funded programs [p. 73]. Highly innovative programs in Europe include those in the Emilia Romagna region in Italy, in Denmark, and in the Baden-Württemberg region of Germany [p. 74].

EDUCATION. What about the workforce? Is it adequately trained for the manufacturing challenges of today and tomorrow? Most European university programs require actual industrial experience. Germany's Technische Universität in Berlin, for example, requires a 26-week-long practicum in industry. In the United States, manufacturing education is receiving new attention at the graduate level. One unusual program is the Future Professor Program at Stanford University, in California, which is aimed at training faculty in the manufacturing field [p. 76]. Another new focus, this time for the middle- and high-school level, is a traveling laboratory that gives students hands-on experience with the latest manufacturing technologies. It is sponsored by the National Center for Manufacturing Sciences, Ann Arbor, MI [p. 79].

WHAT NEXT? Probably an even more extensive use of the information and communications technologies in manufacturing is what has come to be known as the Intelligent Manufacturing System, or IMS, currently under development by international teams [p.82].

By now, many engineers crave easily available, practical information on the manufacturing field. More than 76 percent of the respondents to a 1992 survey of members of the IEEE, the Society of Manufacturing Engineers, and the Instrument Society of America felt a need for applications-oriented information for electrical, electronics, and computing design and manufacturing engineering. For more on various information sources, see p. 85.

Putting it all in perspective is an essay that places today's computer-integrated manufacturing (CIM) in the context of the manufacturing evolution of the last 200 years [below].

200 years to CIM

Ramchandran Jaikumar Harvard Business School

Manufacturing technology is the technology of process control. It is machines, human labor, and the organization of work brought together to control a manufacturing process. Whenever the approach to process control shifts significantly, a host of parameters changes. These shifts suggest six epochs in manufacturing, each being in essence a solution to a problem in process control [see table].

What triggers a new epoch in manufacturing is the development of new technology that represents a watershed in the conception of a particular problem. The new technology dictates changes in the nature and organization of manufacturing and in the machines used to effect those changes. Most of the gains in productivity, quality, and process control outlined in the table occurred while such changes were being assimilated, usually over a period of about 10 years.

The English system of manufacture originated in the late 18th century with the invention of general-purpose machine tools, such as lathes, that could be used to fabricate a variety of workpieces. This development severed a product's function from the process used to make it, endowing that process with a life of its own. As a result, improvements in fabrication could be made independently of product considerations. Once technology was freed from the constraints of the product, it flowered rapidly, transforming the technological landscape within half a century.

The American system of manufacture that emerged in the mid-1800s emphasized precision and the interchangeability of parts. Whereas the English system had sought the best possible fit between components, the new system aimed at the greatest possible clearance without loss of functionality.

MANAGING VARIANCE. Clearance accommodates variance, and the management of variance became the hallmark of the American system. To achieve the required precision, limits were prescribed and implemented by means of special-purpose machines and gauging and inspection systems. Interchangeable manufacture reoriented the thinking of engineers away from the fabrication of individual components and toward mass production. Moreover, it separated not only fabrication from assembly, but also the different operations that go into fabrication from one another.

The era of scientific management began in the late 1800s. It was predicated on the work of Frederick Winslow Taylor, a U.S. mechanical engineer whose principles of manufacturing management came to be known as Taylorism. Recognizing that the workers themselves were limiting the speed and efficiency of machines, Taylor advanced the notion that these activities could be measured, analyzed, and controlled with techniques analogous to those applicable to physical objects. Using job analysis and time study, he determined a standard rate of output for each job. This approach, coupled with the standardization and control of machines, produced a hitherto unknown level of precision, narrowed the scope of work, and left nothing to the worker's discretion. It placed control in the hands of management, which could monitor a worker's productivity by comparing his or her output against a standard.

Next came the era of process improvement, in the mid- 20th century, based on statistical process control (SPC). Invented in the United States in the '30s, SPC assumes that machines are intrinsically imprecise, since the identical procedure will produce different results on the same machine at different times. Its emphasis on "outliers" (out-of-control situations), rather than on mean performance, directs management's attention away from the worker and toward machine variance.

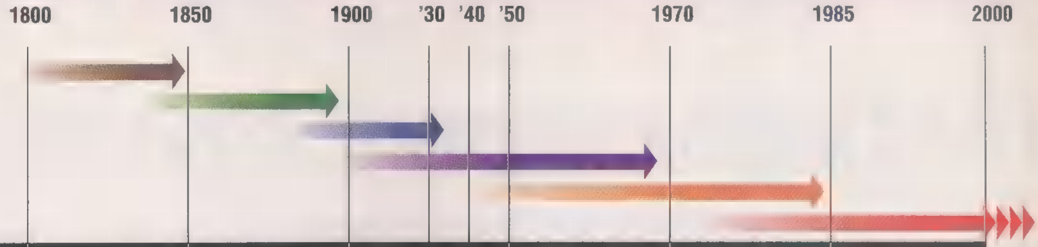
Whereas scientific management conceives of manufacturing problems in essentially static terms, emphasizing coordination and instituting process parameters, SPC is concerned with the dynamism of processes. Consequently, it shifts management responsibility to the quality control function, and views information about process parameters independently of the physical processing of information. Collectively, these changes made it possible to observe and study the efficacy of processes.

Numerical control (NC) arrived in the 1970s with the microprocessor. The technology had originated in a program funded by the U.S. Air Force in the 1940s, but it took the economical and reliable microprocessor-based controller to render it viable. NC combines the versatility of general-purpose machines with the precision and control of special-purpose machines. It emphasizes not only monitoring but also controlling machinery, and rates experimentation and learning above diagnostic skills, and adaptability above stability. It is efficient on a much smaller scale. The engineering focus overall switches from quality to systems. These shifts transform work into a more scientific, abstract, and comprehensive endeavor, one that is subject to continual change. It also implies the need for a complete restructuring of the organization of work and the nature of the firm.

ENTER CIM. Manufacturing entered the computer-integrated era in the late 1980s. Computer-integrated manufacturing (CIM) is based on information about, and models of, functional expertise that make it possible to examine and systematize, the interactions between functions. Recognizing these interactions and predicting their consequences constitute system intelligence, which, with respect to product and process performance, becomes a surrogate for organizational intelligence. With CIM, systems science yields to the management of intelligence. Versatility, in the form of new products and processes, becomes the primary driver, and the ability to generalize and abstract from experience the requisite skill.

The systems enabled by CIM are extraordinary. Silicon wafers are stepped through a wash sequence by an operator at a personal computer who has preset recipe parameters; meanwhile, a microprocessor-based controller operates the complex of valves, safety devices, and sensors in a cleanroom; every half-second a data center queries each of more than 110 sensors on turbine generators scattered throughout a

Evolution of manufacturing



	The English system of manufacture	The American system of manufacture	Scientific management (Taylorism)	Process improvement (statistical process control)	Numerical control	Computer-integrated manufacturing
Number of machines	3	50	150	150	50	30
Minimum efficient scale (number of people)	40	150	300	300	100	30
Indirect/direct labor ratio	0:40	20:130	60:240	100:200	50:50	20:10
Productivity increase over previous epoch	4:1	3:1	3:1	3:2	3:1	3:1
Rework as fraction of total work	0.8	0.5	0.25	0.08	0.02	0.005
Number of products	∞	3	10	15	100	∞
Engineering focus	Mechanical	Manufacturing	Industrial	Quality	Systems	Knowledge
Process focus	Accuracy	Repeatability	Reproducibility	Stability	Adaptability	Versatility
Control focus	Product functionality	Product conformance	Process conformance	Process capability	Product/ process integration	Process intelligence
Organizational change	Breakup of guilds	Staff/line separation	Functional specialization	Problem-solving teams	Cellular control	Functional integration
Work philosophy	"Perfect"	"Satisfy"	"Reproduce"	"Monitor"	"Control"	"Develop"
Skills required (machine operator)	Mechanical craft	Repetitive subskill	Repetitive subskill	Diagnostic ability	Experimentation	Learning generalizing, abstracting

Source: R. Jaikumar, "From Filing and Fitting to Flexible Manufacturing," Harvard Business School working paper, No. 88–045, Boston, 1988.

large geographic area and adjusts their operation to extend their availability.

Thus manufacturing has progressed from an art to a science. The first three epochs embraced mechanization, with manufacturing conceived in terms of increasing efficiency and control. Capital increasingly replaced labor, and economies of scale ensured progress. The engineering focus was on machines, and labor was required to adapt to machines and, ultimately, to become yet another machine. Concurrently, machines themselves grew more elaborate and proficient. The governing principle was greater and greater mechanical control.

The glue that binds a collection of machines into a manufacturing system is information processed by human beings. In the last three epochs, previous trends in mechanization have reversed themselves. Now the emphasis is on versatility and intelligence, the substitution of intelligence for capital, and economies of scope. Machines have come to be viewed as extensions of the mind that can enhance the cognitive abilities of human beings. This shift, based on the versatility of information technology and freedom from mechanical constraint, suggests new managerial imperatives: build small, cohesive teams; manage process improvement, not just output; broaden the role of engineering management to include manufacturing; and treat manufacturing as a service.

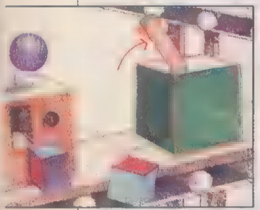
Each of the six manufacturing epochs focused on a particular aspect of process control—from accuracy, precision, and reproducibility to stability, adaptability, and versatility. The long-term viability and manufacturing competence of today's firms hinge on how they manage the latest stage in this evolution.

A SOCIAL DIMENSION. But more is involved than technology and industrial performance. The trend is clearly toward eliminating intermediaries and recruiting fewer, more highly skilled, and multidisciplinary workers. As yet this workforce does not exist and the obstacles to its creation are numerous. Moreover, many workers who feel "empowered" in this new manufacturing context also find that they are working longer hours for less pay. Finally, all the efficiency and productivity improvements in the world will avail companies little if their customers are ultimately reduced to unemployment and poverty. An understanding of the evolution of process control must be applied not only to the improvement of manufacturing, but also to the human and social consequences, both positive and negative, of that improvement. If it can bind business, the community, and government into a cohesive team, such an understanding could usher in not just the next era in manufacturing but also a second renaissance.

ABOUT THE AUTHOR. Ramchandran Jaikumar has been for 13 years a member of the faculty of University's Graduate School of Business Administration, in Cambridge, MA, and is currently a director of research. He was awarded the Frederick Winslow Taylor Medal in 1988 by the American Society of Mechanical Engineers for distinguished contributions to the management of technology, among other awards. He has published widely in academic and professional journals, contributed to a number of books, and been an advisor to the Congressional Office of Technology Assessment and the U.S. Senate Subcommittee on Science, Technology. and Space He serves on a number of committees of the National Research Council.

The flexible factory: case studies

Technology is making that seeming oxymoron, custom mass production, a reality. Today factories are coming on line that are agile at tailoring goods to a customer's requirements, without halting production for a tooling change. In one such factory—Motorola Inc.'s Fusion facility—the product and manufacturing design are so intertwined that a product is manufactured virtually (in the technical sense) while the order is taken.



Some companies, like National Bicycle Industrial Co. and Applied Digital Data Systems Inc., blended the skills and intelligence of people with the tireless perfectionism of robots in order to make better products economically. Yet at the Charles Stark Draper Laboratory Inc., the extreme precision needed could be achieved only through automation.

A common theme among the case studies in this section is how companies have benefited from the risk of developing flexible manufacturing facilities. Nowhere is this clearer than in the case of Allen-Bradley Co., whose flexible eight-year-old contactor line continues producing profits.

Companies at the forefront of manufacturing are learning how to rapidly prototype products, not merely to evaluate the product itself, but also to smooth the way to agile manufacturing. Industry is on the brink of the virtual factory—a place where the product manufactured depends solely on the imagination of the designer, and the variety of models produced (always with maximum economy) depends only on the whims of the market.

A quick look at rapid prototyping

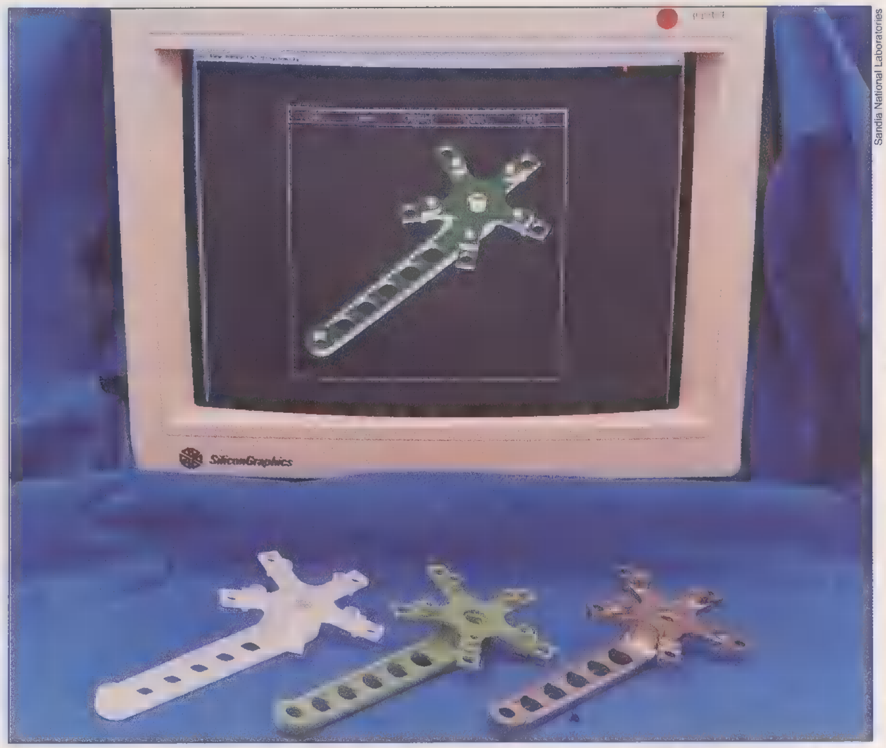
Richard Comerford Senior Editor

Today, businesses are deploying several techniques for accelerating design and production. Among those that have already aroused much interest are concurrent engineering and just-in-time manufacturing, as well as electronic design automation tools such as logic synthesis. Thanks to these techniques, electronic components may be produced in just weeks.

Until recently, however, the housings and the electromechanical parts also needed for electronic systems took many months to fabricate. Further, if those parts did not mate properly or function correctly, the extra tooling-fabrication cycle could give competitors just the break they needed to get to market first.

No wonder, then, that companies today are excited about the swiftly progressing field of rapid prototyping. In a paper delivered last May at the Rapid Prototyping and Manufacturing '93 Conference in Dearborn, MI, authors Clinton L. Atwood, Gerald D. McCarty, and Brian T. Pardo of Sandia National Laboratories' Rapid Prototyping Laboratory, Albuquerque, NM, stated: "The introduction of rapid prototyping machines into the marketplace promises to revolutionize the process of producing prototype parts with production-like quality."

CRANKING UP. The excitement of the Sandia researchers was fanned by recent experiences with modern rapid prototyping systems. To establish benchmark data, the group used stereolithography and selective laser sintering equipment as part of a technology-transfer program to produce a bicycle crank arm for a local bike shop. The geometry of the crank arm was of average complexity [see photo above].



To check out stereolithography (SLA) and selective laser sintering (SLS) processes, Sandia National Laboratories, Albuquerque, NM, created a bicycle crank arm. From the computer-aided design file seen on the screen, the labs' rapid prototyping group made an SLA model [left] to see how the arm would fit with other parts. Then, they made an SLS model [center], from which a mold for the final part [right] was made.

Stereolithography (SLA), the most popular technique for rapidly producing prototypes, was invented in 1982 by Charles Hull, now president of 3D Systems Inc., Valencia, CA, which first commercialized the method in 1986. A stereolithographic system takes information about the object to be modeled directly from a computer-aided design database and builds a solid version of it out of liquid photopolymer. The system's laser sketches a cross section of the product on the liquid, simultaneously curing it. By piling up successive cross sections, the system creates the final, solid form. Sandia used the resultant prototype, built on an SLA-250 from 3D Systems, for fit checking (that is, verifying dimensional accuracy) and proof of design.

To make a prototype part out of the same

material as the final production versions, in a way that replicates an investment-casting (lost-wax) production process, Sandia first builds a wax model with selective laser sintering (SLS).

Following data from slightly modified SLA files, the sintering creates a model by fusing wax powder with a laser. The wax models are then fitted with wax gates and vents, and the resulting assembly is repeatedly dipped into a binder and a ceramic powder to build a ceramic shell. Once the shell is complete, the wax is melted out, leaving a mold for molten metal.

Creating a wax model in this way takes only five days, versus several months by traditional methods, and reduces the cost of obtaining prototypes by as much as 90 percent. As a bonus, the technique also electronically documents the entire process, from design through production.

POWER TOOL. Sundstrand Aerospace's Electric Power Systems Division in Lima, OH, first worked with rapid prototyping in June 1991, for part of an aircraft's variable-speed, constant-frequency electric system. The customer had encountered field problems with a current-transformer/electromagnetic-interference module and wanted them corrected in just four months.

A month after starting the project, the group had a prototype mock-up. Engineers fabricated detailed polyurethane parts using stereolithography and silicone rubber molds. Printed-circuit boards were made from glass epoxy sheets, and interconnecting flex circuits were simulated with folded paper. The mock-up, built in just a week's time, won the customer over.

Rapid prototyping has dramatically changed the way the company works, said Richard Gee, manager of mechanical design and development. Gee called the technique "not just a technology by itself, but a process that extends into every aspect of the development cycle."

CASE STUDY
Motorola Inc.

Pocket pagers in lots of one

Russ Strobel and Andy Johnson Motorola Inc.

During the 1980s, Motorola Inc. started aggressive programs to reduce cycle time and improve quality. Its highly regarded Six Sigma program for reducing defects to 3.4 per million parts [see p. 43] has inspired a number of manufacturing innovations. Among them is the new Fusion program at its Paging Products Group in Boynton Beach, FL.

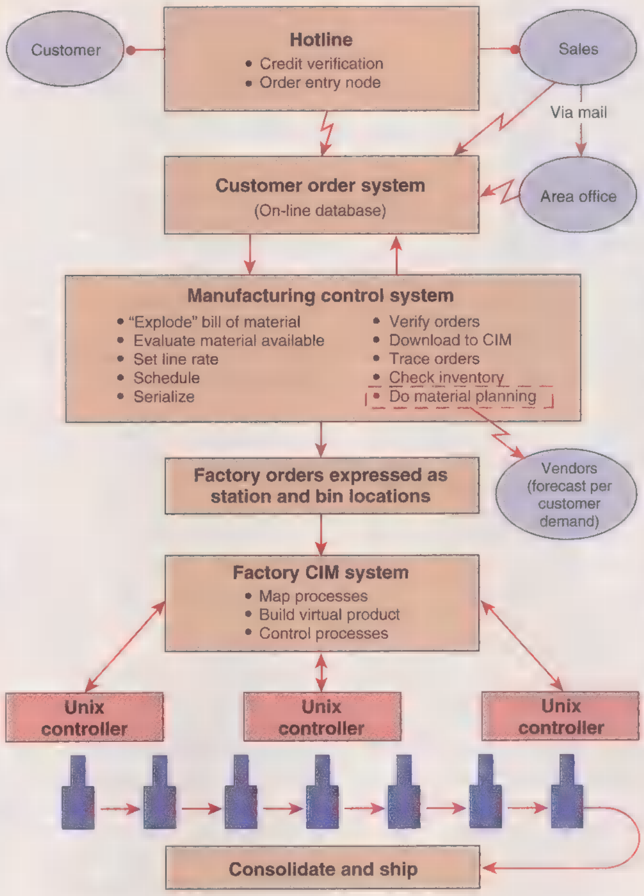
The evolution of computer-integrated manufacturing (CIM) at this group began in the mid-'80s as a competitive response to comparable but cheaper products from offshore firms. At that time, Motorola decided to change its manufacturing strategies.

The earlier Motorola prescription had been to assemble products offshore, retrieving populated printed-circuit boards from plants in Singapore, Puerto Rico, and the South Pacific. Manufacturing costs were lowered, but the cumbersome process was not fast enough to respond to customer requirements or, in the long term, the competition. So in 1985, Motorola began planning to automate the manufacture of one of its upcoming paging products, Bravo, at its Boynton Beach facility.

Development of the product was well under way. Nevertheless, the so-called Bandit project was chartered to create a fully automated system to manufacture Bravo pagers domestically for less than traditional methods could. A small team of process, product, automation, and computer engineers was charged with creating the line in 18 months; by 1987, the line was working and demonstrating that advanced CIM was truly cost competitive.

In the six years since then, Motorola has advanced to the Fusion manufacturing system that is bolstered by easy customer access [see above figure]. Fusion had its genesis in the desire to introduce the most advanced new family of paging products in the world. The product family, code-named Fusion, was revolutionary enough to require a specially designed CIM factory. The factory envisioned would also enable advanced product development and distribution. Since the word "fusion" signifies unification and integration, it was chosen as the name for the product, the process, the factory, and the team's philosophy.

Fusion's CIM and automated assembly system can manufacture a wide variety of different products. The factory's computer system processes each order and relays it to the factory floor, where the machinery



Electronically speaking, Motorola's Fusion process makes the distance between the customer and manufacturing extremely small. A customer can order a pager over a "hotline" phoneline, choosing features by describing them in plain English. The order can then be automatically translated into the data the factory needs, checked out by theoretically building it on a computer, and sent to the factory floor for fabrication—while the customer is still on the line.

Defining terms

Agile manufacturing system: a system that can fabricate different objects simultaneously, without having to be shut down for retooling.

Cyberspace: a hypothetical area in which electronic information, as well as objects and events simulated by computers, are imagined to exist.

Cell controller: a computer system used to control a group, or cell, of computers in a factory and is itself controlled by a higher-level computer.

Injection molding: a process for producing highly accurate objects in which the material used to form them is injected into a mold under high pressure to ensure that it solidly fills the mold.

Line controller: a computer that is ultimately responsible for the operation of an assembly line.

Station controller: a computer usually dedicated to the control of a single manufacturing operation at one particular work site.

Virtual: an adjective used to describe the use of computers to realistically create, manipulate, and display objects or events.

builds that custom product in a "lot size of one" with no delay in the factory's cycle time. In other words, the order triggers an instantaneous changeover.

Before Fusion, Motorola factories could accommodate product variations such as housing colors, vibrate options, alerting options, and frequency, to name a few. However, circuit-board shape remained physically the same, limiting truly agile manufacturing. The leap forward with the automated Fusion Factory is its ability to process physically different pagers—including the circuit board—on the same production line.

While Fusion incorporates many things learned about automated manufacturing since the Bandit system was begun in 1985, it was a totally new project from the ground up. It enhanced the environment for developing new products, not just for manufacturing them faster. Backed by a corporate investment of over US $3 million in engineering tools, the Fusion design team understood the need to exploit the most advanced CIM capabilities.

RISKY BUSINESS. Development of the Fusion product itself involved risk. As envisioned by the designers, it called for an entirely new core of advanced electronics for future paging products. The new ICs would be denser, with very high levels of functional integration, while using low-voltage technology. In addition, an integrated selectivity receiver IC never before used in pagers would replace ceramic filters. Compounding that risk was the need to introduce the next level of manufacturing technology—agile manufacturing. In an agile manufacturing system, physically different products are assembled on the same line with no tooling changeover.

Projects that followed Bandit had used existing electronics developed for the original pager, primarily enhancing the Bandit program's product-manufacturing techniques. Departing from this practice, Fusion intertwines development, engineering, and manufacturing. It allows engineers to create (not just manufacture) future new products right on line.

At the same time, the Fusion Factory shows several major improvements over other advanced manufacturing operations. One is the dynamically configurable workflow paths. Other manufacturing facilities were created as serial lines; if one process, such as a robot part insertion, was stopped, the entire work output was interrupted. Even though mean-time-between-failures statistics for manufacturing equipment in advanced serial-process factories remain quite good, finite amounts of downtime occur during feeder jams, part exhausts, and machine malfunctions.

The Fusion Factory embodies a combination of parallel and dynamic systems for everything, as seen on p. 31. In the front end of the manufacturing process, there are two sections to populate and two to reflow-solder circuit boards; at the back end, there are dual assembly, test, and packing sections. Along the work flow paths, the computer control system constantly monitors equipment status. The self-monitoring equipment sends status information to the control system to allow it to reconfigure the system as needed.

In the front end, each downstream robot can do the job of its upstream counterpart if the latter goes down. Although each robot performs a different operation, all are flexible enough to take on other operations when needed. Robot assembly is divided into two segments and, if one segment goes down, Fusion automatically routes products to a parallel segment.

This is true for all manufacturing functions in the front and back ends. The computer control system tracks the available capacity of the entire manufacturing system so that products can be dynamically rerouted in real time along the most efficient path to completion.

Another major advantage of Fusion is its state-of-the-art computer control system. Composed of reduced-instruction-set computers running Unix tied together with an Ethernet, it represents a significant modernization of the architectural concepts proven years ago in the Bandit program with complex-instruction-set computers connected by RS-232C links.

The actual manufacturing equipment at Motorola's Fusion operation is similar to other electronic assembly sites. What sets Fusion apart and has pushed advanced manufacturing forward is the way that equipment is linked into the computer control system and the software that runs the system. They automatically translate a customer order, in the form of statements like "I want a black pager that plays 'Yankee-Doodle Dandy,'" into a unique bill of materials and a set of options for each pager to be built. After the pager is packed, the system updates the material inventory status to indicate that a set of parts has been shipped out of the Fusion Factory.

Earlier systems also used a Unix-based line controller. But they had to communicate with the line through several more layers of older-technology computers, called cell controllers and station controllers. Typically, there were several layers of cell controllers between the line controller and the station computer.

FEWER LAYERS. Fusion eliminated the cell layers. It utilizes a Unix-based line controller and has Unix-based station controllers on each robot. The station controllers and the line controller are all linked together by an Ethernet network. They are equivalent machines, so programs can run on any computer within the system. No hierarchy or limits to flexibility and agility hamper the control system.

Fusion's comprehensive tracking system is another plus. Older manufacturing systems tracked pallets; products were assembled on pallets, each with an engraved number to enable communication between the workstation and the computer control system.

To support agile manufacturing, Fusion tracks the product itself instead of tracking the pallet. Unique marks on each circuit board identify that unit (by the customer's serial number) from the very first process in the manufacturing system.

The first station in the line is a laser that marks each printed-circuit board with a machine-readable customer serial number. Each station has a camera that reads the number and, after decoding it, requests the specific build information from the line controller. Earlier systems associated the customer serial number with the pager further downstream in the process.

In the Fusion Factory, manufacturing staff monitors the inventory that exists on the manufacturing floor. All manufacturing materials received by the factory are bar-coded by their suppliers. The feeder locations are also bar-coded. As components are loaded into feeders, the bar code from the component reel and feeder is automatically recorded. Thus, the exact date code and lot of material used to produce a particular pager can be displayed at any time by

Rapid tooling

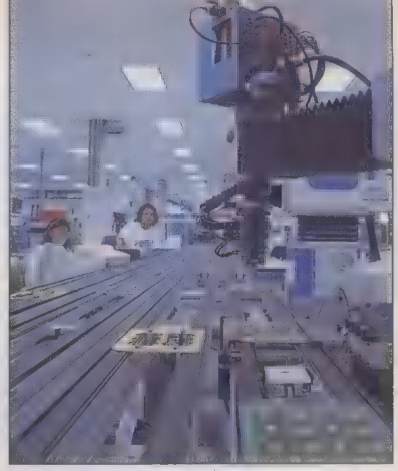
Great strides were made during the Fusion project to expedite tool production while eliminating drawings and other paperwork. Computer-aided-design (CAD) modeling allowed engineers to easily visualize the tool's cavity, core blocks, and inserts, and to greatly simplify them, which further sped fabrication. As a result, fabricating injection-molded tools in a matter of days has become commonplace.

To design and fabricate tool molds, engineers first create solid models of the parts to be molded on CAD stations. Once a part is designed, engineers create a solid block model around the part. Computers perform a Boolean operation to subtract the part from the block, leaving a void. Engineers then split this model block along parting lines, thereby producing the individual solid models of inserts that fit into the mold. For most parts, complete design of a mold insert takes less than an hour.

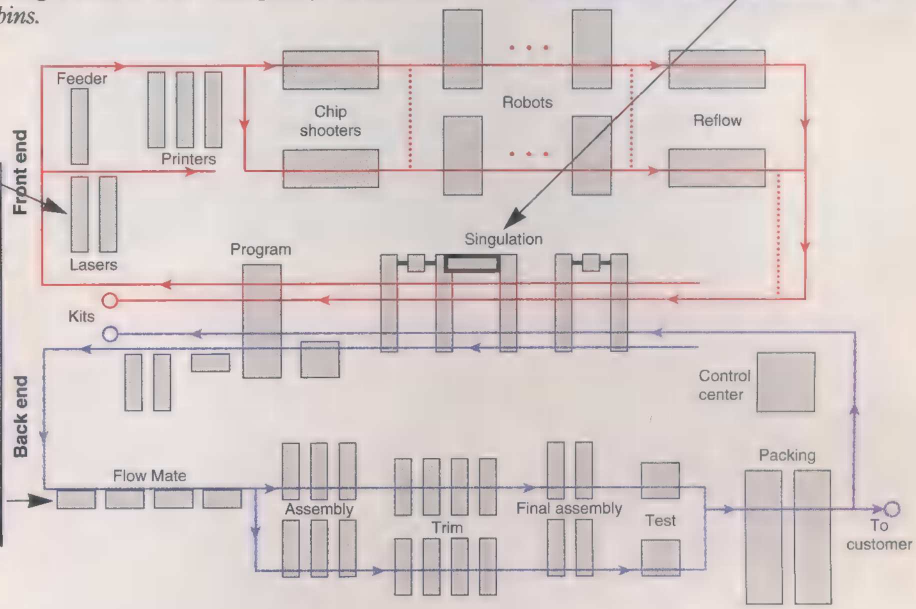
Machinists are involved throughout the insert design activity. They can point out in real time where special accommodations are needed to simplify machining and eliminate complex operations or electric-discharge machining work. Finished insert designs can be machined directly from the computer database, using computer numerically controlled (CNC) tools, with minimal dimensioning required for block sizes.

The result at Fusion was a complete set of insert blocks two days after part design. Within a week from the initial design concept, thousands of parts were being molded by suppliers and available for assembly on the factory floor. —*Charles Hahs*

An agile line in constant motion



The Fusion Factory very agilely builds products in lot sizes of one. At upper right, the process begins when the feeder puts a printed-circuit board onto the line. It is marked by laser with the customer's unique number. As the board flows down the line, the number will be read by each machine. In the middle of the factory is the singulation area, which acts like a railroad switching yard to more individual units between lines. The Motorola-designed Flow Mate at lower left assembles physically different units using a robot arm to choose parts from different bins.



the computer control system.

Once, the relationship between incoming orders and manufacturing capability was marginally adequate in most factories. While manufacturing may have thought it had the inventory or the correct process sequences to make a product, occasionally the product ordered could not be assembled on the factory floor for lack of a component or correct build data. The missing part or data would make it hard to fulfill the customer's order on schedule.

VIRTUAL MANUFACTURING. Fusion cannot release an order that is not manufacturable to the factory floor because the system builds the product in cyberspace in microseconds before letting the order enter the manufacturing system. The software that builds the virtual product was created by Motorola engineers specifically for this purpose.

This virtual manufacturing system ensures that all the processes are on-line and that inventory required to build that particular product is at the stations before the customer's serial number is inscribed on the circuit board. Should Fusion's virtual manufacturing system find a missing link in the process, that specific order will be diverted to another computer file and returned to order entry or marketing with a notation explaining the missing or incorrect data. After resolution, the order returns to manufacturing.

ACHIEVING FUSION. Concurrent engineering was used in previous advanced manufacturing programs—Bandit, Bravo Express, Wrist Watchpager, Advisor—but internal development groups rate Fusion as Motorola's most ambitious concurrent engineering team. In past manufacturing programs, product developers moved to the manufacturing floor. To push technological innovation in Fusion products, manufacturing teams relocated to product development labs.

As the new product was designed, process developers, product designers, computer specialists, and automation engineers all worked concurrently in the same lab. Their input in this environment, via their own professional disciplines, helped to realize the vision of the new product.

The use of Unix-based engineering workstations was also vital in achieving the Fusion program's goals. All product development engineers at Motorola's Paging Products Group use them. New designs in the engineering lab, such as converting a pager from one frequency band to another, are first developed and simulated on an engineering computer using various electronic design automation tools to simulate the frequency and mechanical performance of the design.

After confirming that the parts for a new product are available on the manufacturing floor, product engineers send the design over the network requesting that the Fusion Factory build several dozen pagers, never having prototyped a single unit. Motorola calls this ability of the Fusion Factory a "link to engineering."

TECHNICAL INNOVATIONS. With capabilities such as these, Fusion provides a new model of what agile manufacturing can be. The routine ability to build physically and functionally different units from designs created in the engineering lab, transmitted to the factory floor, and produced without a prototype is a new benchmark for agile, world-class manufacturing.

To reach this level, the group benchmarked other world-class manufacturing sites (as well as learning from internal events) to decide what techniques were best for the Fusion program. Engineering management's practical philosophy has been to reject the not-invented-here syndrome. The Bandit program, and all its successors up through Fusion, mandated a development and implementation cycle too short for everything to be invented. So if there was a good, freely available idea out there, Motor-

How agile manufacturing evolved for Motorola's pagers

Project name (product) time frame	Control	CIM response, sec.	Quality	Mfg. engrg. integration	Processing	Technology	Contribution
Bandit (Bravo) 1987–1990	▪ Data-driven factory, lot size of 1 • Cell boundaries • Real-time line-rate setting ▪ Textual user interface	4	• 5.2 σ • Real-time statistical process control • Custom quality reports	• Manual	▪ Single band ▪ One board per pallet	▪ Soft automation ▪ Driven by bill of materials ▪ Product redesigned for automation	▪ Proved CIM system approach ▪ Provided base for future systems ▪ Handled lot size of 1 ▪ Validated approach as cost-competitive
Mermaid (Wrist Watch Pager) 1989–1993	▪ No logical cell boundaries • Textual user interface	2	• 5.2 σ • User-configurable quality reports	• Manual	• Single band ▪ Multiple boards per pallet ▪ Kits/ sub-assemblies	▪ Over conveyer test • Laser trimming ▪ No-clean reflow • Array manufacturing ▪ Vision assist	▪ Enabled handling of high-density products
Cobra (Advisor) 1990–present	• Auto queue control • Fault-tolerant hardware • Routing enforcement • Automatic order releasing • All controllers use Unix	1.5	• 5.5 σ • *Ad hoc* reporting	• Manual	▪ Multiple bands	▪ Thermode reflow ▪ Hot-bar process	▪ Validated continuous improvement process
Speedy (Bravo Express) 1991–present	▪ Plant host functionality • Mfg. build aids ▪ Back-end robot control	1	• 5.6 σ ▪ *Ad hoc* reporting	• Electronic ECP/ECN • Material movement across lines	• Multiple bands ▪ Multiple colors	▪ Front-end automated test • Random-access tray feeder	▪ Reused 75 percent of Bandit capital • Speeded retooling for new product
Fusion (Bravo Encore) present–?	▪ Streamlined (fewer layers) ▪ Unix-based systems ▪ Unix station controllers • Dynamic functionality • Redundant, nonserial manufacturing lines	Look ahead	• 6 σ • Real-time statistical quality and process control ▪ Custom quality reports	▪ Link to engineering ▪ On-the-fly product changeover ▪ Instant prototypes ▪ Bill of materials automatically generated ▪ Standardized messaging interface	▪ Multiple products ▪ Pallet-independent unit tracking ▪ Array processing • Product designed for assembly (DFA tripled)	▪ Array processing with on-line singulation ▪ Laser etching ▪ Common test hardware and software • Redundant manufacturing system	• Provides flexible, agile manufacturing • Increases inventory turns to over 10 • Supports infinite product combinations • Allows scaling of mfg. capability • Creates a product-independent control system • Produces multiple products on same line

CIM = computer-integrated manufacturing; DFA = design for assembly; ECP/ECN = engineering change proposal/notice.

ola's engineers would implement it.

The company could therefore focus on the overall objective—creating a state-of-the-art advanced manufacturing system—and not reinvent the wheel. The innovation is in pushing technology toward better performance, reliability, and customer satisfaction.

Engineers examined field issues and customer comments on existing products, categorized them, and determined root causes of reliability problems. They were thereby able to design those problems out of the product. The new pager operates at a lower voltage with many fewer parts, increasing battery life and optimizing operational reliability.

The Fusion team continually referenced "design for assembly" (DFA) efficiency guidelines during product evolution. As a result, assembly of the new pager was rated much more efficient than the product family it replaces.

Supplying pagers is truly a "lot size of one" business. Each is unique. In addition to programming variations, there are a multitude of physical variations that require each pager to be built with its own unique bill of materials. To more efficiently process customer requests for pagers, Fusion's order entry system transmits such data to the line controller within minutes, for production to the customer's requirements within hours.

Furthermore, flexibility designed into the Fusion Factory enables Motorola to build virtually any portable electronic product—from calculators to personal digital communicators—as long as the design is represented on the computer system and parts are available to the assembly robots. Many of Fusion's concepts have been applied to Motorola factories worldwide.

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Andy Johnson is a member of the manufacturing engineering support team at the same facility involved in the Fusion Factory implementation. He has received excellence awards from the South Florida Manufacturers Association for his work.

Charles Hahs is a mechanical engineer and was involved in product design, rapid prototyping, and computer verification for Fusion.

CASE STUDY
National Bicycle Industrial Co.

Bicycles on a personalized basis

Trudy E. Bell Senior Editor

Say "Panasonic," and most people around the world think of consumer electronics. But in Japan, Panasonic is also a respected name in bicycles. It is used by Japan's second largest manufacturer of bicycles, selling some 700 000 a year in that country alone—about 9 percent of the Japanese market of 8 million bicycles a year.

Since June 1987, 70 000 Panasonic bikes have been semicustom machines built to the specifications of individual consumers by National Bicycle Industrial Co. Ltd. (NBI) in Osaka, a division of Matsushita Electric

Industrial Co. Ltd. No two bicycles the factory has produced are alike. These personalized products are built through a flexible manufacturing system that combines just-in-time processing with robots, computer-aided design and manufacturing (CAD/CAM), and the skills of master craftsmen.

Designing a flexible manufacturing system was a completely new experience for NBI, as it had originally made its mark with mass production and mass sales to dealers through companies owned by Matsushita. When the pioneering flexible system was introduced, in June 1987, it created a great sensation among general industries in Japan. Rival firms felt virtually obligated to institute their own such operations, the first of which started competing with NBI ■ year and ■ half later. But only NBI has been well accepted in the marketplace.

CUSTOM VS. PERSONALIZED. A custom bicycle is one whose diamond-shaped frame has been built to the purchaser's individual measurements (torso length, leg length, and arm length) and style of riding (racing, touring, or off-road riding, all of which require somewhat different frame angles, frame dimensions, and tube gauges for optimum performance). The frame is then fitted with the purchaser's choice of components (gears, pedals, brakes, handlebars) and accessories. A wholly custom bicycle can costUS $2500 to $3500 or even more, and can take two months to make because the framebuilder does all the metal-working by hand.

In terms of options, prices, and times, a personalized Panasonic bicycle falls midway between such ■ uniquely designed custom bicycle and ■ limited-choice mass-produced model. Altogether, NBI offers more than 11 million combinations of features.

For a road bike, say, customers choose one of 10 styles of frame from 15 sizes of chrome-molybdenum or chromoly steel (from 46 cm to 60 cm in 1-cm increments) or 13 sizes of aluminum or carbon fiber. They can specify one of three head angles for the front fork, six variations in the stem length for the handlebars (to fine-tune for torso length), four in the handlebar width (to adjust for shoulder width), and two in gearing. Then comes the fun part: choosing among 191 color schemes of up to three colors each, and deciding which of two places to put ■ decal bearing the owner's name in any of five different styles of type.

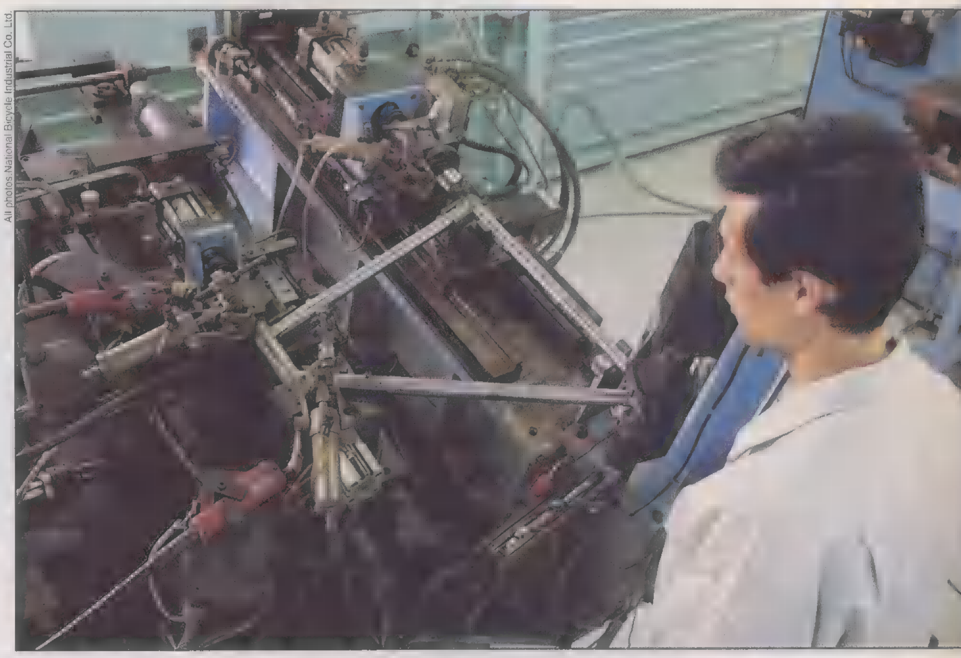
At one of NBI's 1500 pro bike shops in Japan (out of a total of 8000 NBI shops), the customer's body measurements are taken and entered, along with his or her preferences, in ■ detailed order form. That form is then faxed directly to the factory before 2 P.M., where operators immediately enter the information into a computer.

BAR-CODE ORDER SYSTEM. The computer generates a CAD/CAM mechanical drawing of the bicycle to test the frame's design, and assigns a bar-code number for all components. (Among other things, the bar codes let the factory track a bicycle's progress and answer later customer inquiries immediately.) The factory computer also enters an order for correct-sized parts to NBI's vendors. Since NBI sends out parts orders only twice a month, it must do a bit of advance forecasting based on past demand.

At the factory, each bicycle is assigned ■ veteran craftsman, responsible for overseeing the process from beginning to end. The craftsman, who works alongside robots that perform the rougher, more routine tasks, undertakes the finest details.

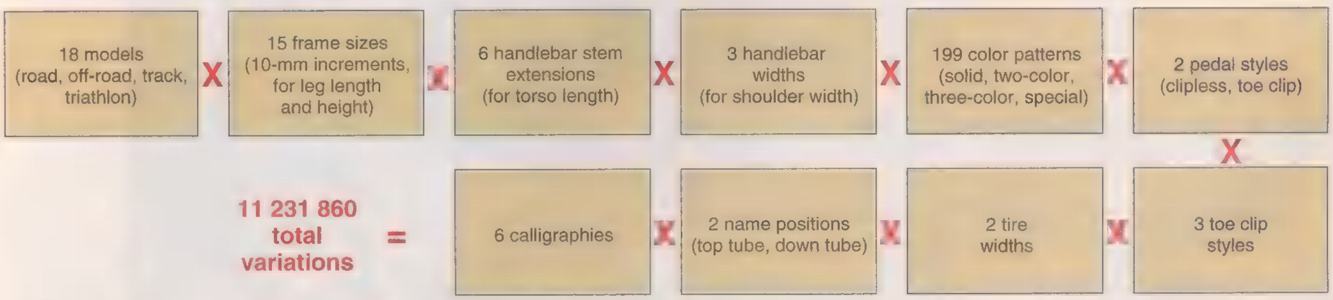
NBI builds bicycle frames only when it receives an order—a true just-in-time (JIT) process. For all the bikes made of chromoly steel and aluminum and for some made of carbon fiber, the three main tubes of the frame's front triangle are automatically cut to length with a machine tool developed by NBI. The computer calculates the exact tube lengths and miter angles, and numerically sets the cutters at the exact position.

For the chromoly steel frame, the three main tubes are automatically brazed together into the frame's front triangle. (Brazing is ■ soldering process in which the tubes are joined using a nonferrous metal—in this case, brass—which has ■ lower melting point than chromoly steel.) Swinging gas burners heat the tubes, whose temperature is automatically monitored by thermal sensors, which in turn automatically control the feeding of the brass wire.

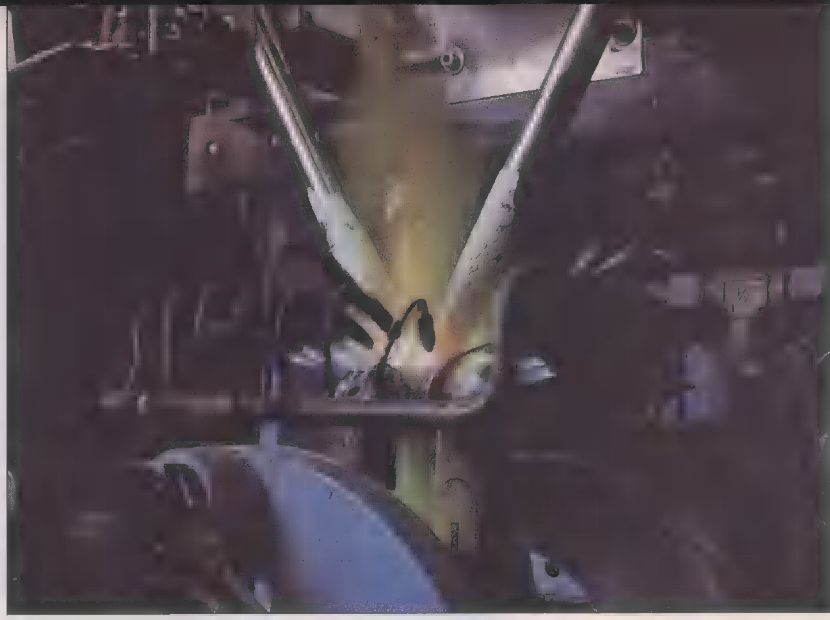


All photos National Bicycle Industrial Co. Ltd

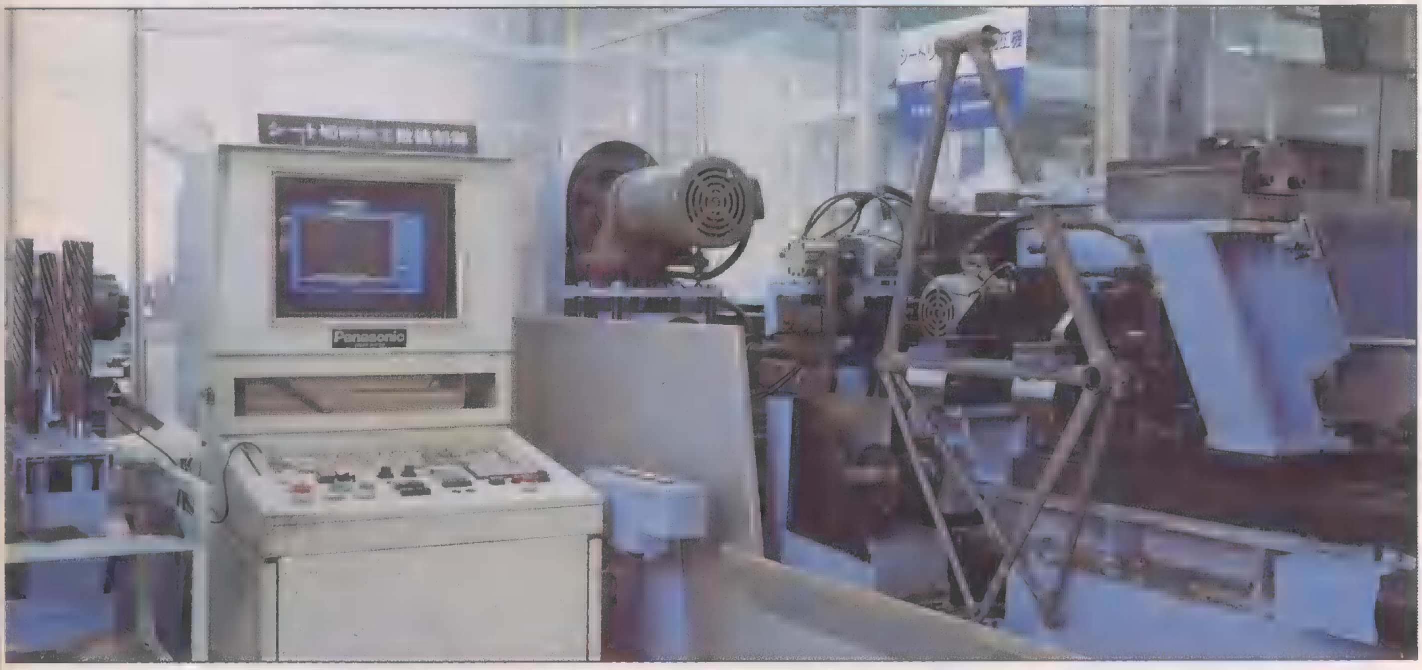
The three main tubes of a chromoly steel bicycle frame are automatically cut [not shown] to the customer's measurements. Then those tubes are automatically assembled into the frame's front triangle by this computer-controlled assembly machine, which makes temporary welds.



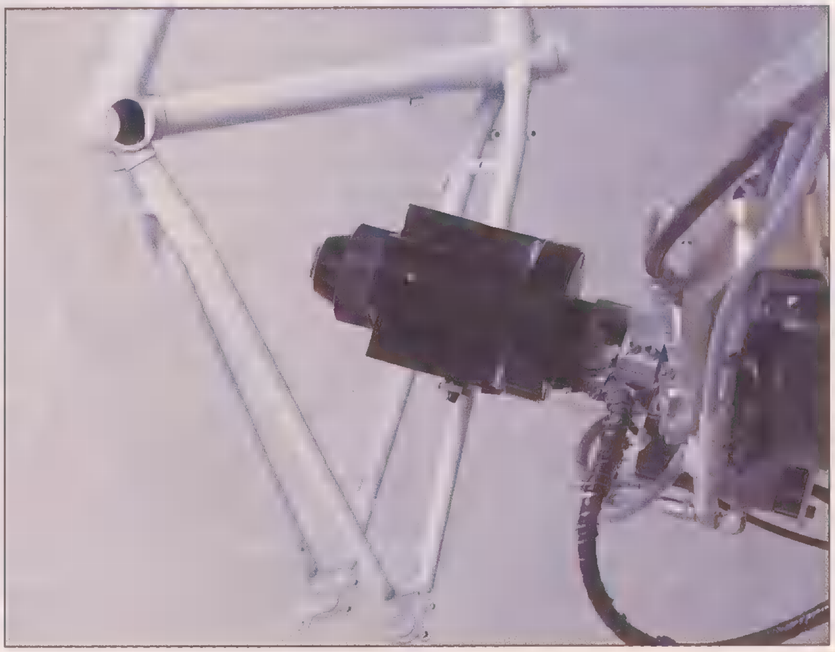
The Panasonic Order System (POS) for personalized bicycles—which relies on a computerized bar-coding just-in-time inventory system—allows the National Bicycle Industrial Co. Ltd. in Osaka to produce one of more than 11 million possible variations and to deliver the product within two weeks, responding to ■ customer's specific measurements and taste. Every bicycle the factory manufactures is unique.



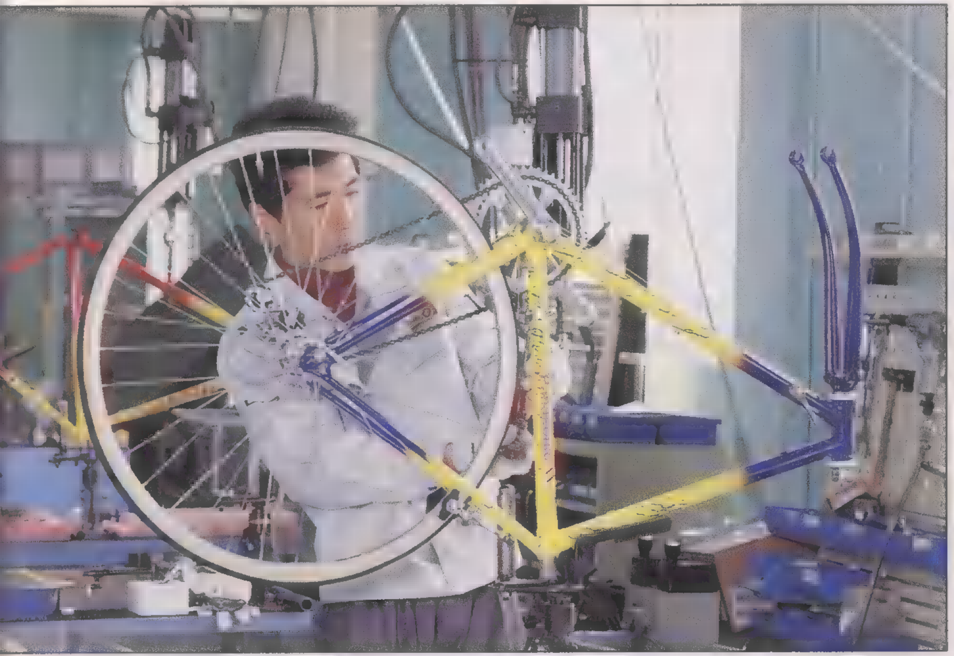
The front triangle of a chromoly steel bicycle frame is automatically brazed (soldered using brass). Swinging gas burners heat the tubes, whose temperature is automatically monitored by thermal sensors, which also control the feeding of the brass wire.



The seat-tube grinding machine automatically makes grooves in the frame for the seat lugs, and then reams and polishes the interior of the seat tube so that the customer can precisely and smoothly adjust the height of the saddle.



A painting robot automatically sprays primer and clear gloss onto the finished frame, following instructions by the host computer. Painting of details is done by hand by a skilled craftsman [not shown].



After being assembled, painted, and stenciled with the customer's name, the bicycle frame goes to a veteran craftsman who adds the parts specified by the bar code, and fine-tunes them.

According to NBI, it is very difficult to distinguish differences in quality, smoothness, and beauty between the factory's automatically brazed lugs and the hand-brazed lugs of wholly custom bikes.

It is with the aluminum and carbon-fiber frames that the flexible manufacturing process of the NBI factory takes custom framebuilders head-on. Since both aluminum and carbon fiber have a melting point lower than brass, the lugs for the aluminum frames and most carbon-fiber frames are glued with adhesives instead of being brazed. In addition, three styles of the most expensive type of carbon-fiber frame can be cast as a unit in ■ custom-proportioned mold—resulting in a monocoque (one-piece) frame.

No matter which type of frame is made, an automatic three-dimensional measuring system checks its dimensions and the data are processed by computer to yield ■ good/no-good decision on a video display. After the master craftsman confirms the customer's color scheme and decal placement by color video display, robots prime and paint the frame in half ■ dozen thin layers—even touching up paint in the frame's corners. The robots are programmed by scanning the customer's bar code, which gives them the data from the host computer. For a two- or three-color paint job, and for the placing of the customer's name onto the top tube, the craftsman takes over. The whole process of building and personalizing the three-tube frames—including the curing time for the multiple coats of primer, paint, and gloss—takes five working days.

The craftsman also assembles all the components (gears, brakes, pedals, and so forth) onto the frame. Components of various sizes are stored, unpacked, at parts stations on shelves. Lights at each station are wired into the computer system. As each order is processed, the lights at those stations holding the relevant parts light up, allowing the craftsman to select the correct part immediately.

The personalized Panasonic bicycle is shipped, partially disassembled for compactness, to the shop where the original order was placed. There, the shop owner completes the assembly and notifies the customer, who also receives both a printout of the CAD mechanical drawing that details all of the bike's specifications and a personal thank-you letter from the company.

NBI's factory produces an average of about 50 to 60 personalized units ■ day. For each bicycle, the production time, including the assembly of components, is eight to 10 working days—approximately double that of the mass-produced, noncustomized article. At an average price of 150 000 yen (US $1300), personalized bicycles are about three to four times as expensive as mass-produced bikes, but about half as dear as fully custom ones.

CASE STUDY
Applied Digital Data Systems Inc.

Display terminals as you like them

Vincent P. Luciano
Applied Digital Data Systems Inc.

In the mid-1980s, Applied Digital Data Systems Inc. (ADDS), like several other terminal vendors, decided to move its manufacturing to the Far East. But the Hauppauge, NY, company soon found that problems with productivity, delivery, and quality outweighed the cost benefits of offshore manufacturing. So in 1989 ADDS risked its survival by returning the function to its original facilities in Hauppauge.

The gamble paid off. Today, ADDS delivers twice as many terminals as it did in the 1980s, with defect-free ratings of about 99 percent, in lot sizes ranging from 1 to 1000 terminals, and with ■ smaller workforce. This success was directly due to a state-of-the-art manufacturing process developed by the company on the basis of input from senior executives, R&D, and engineering.

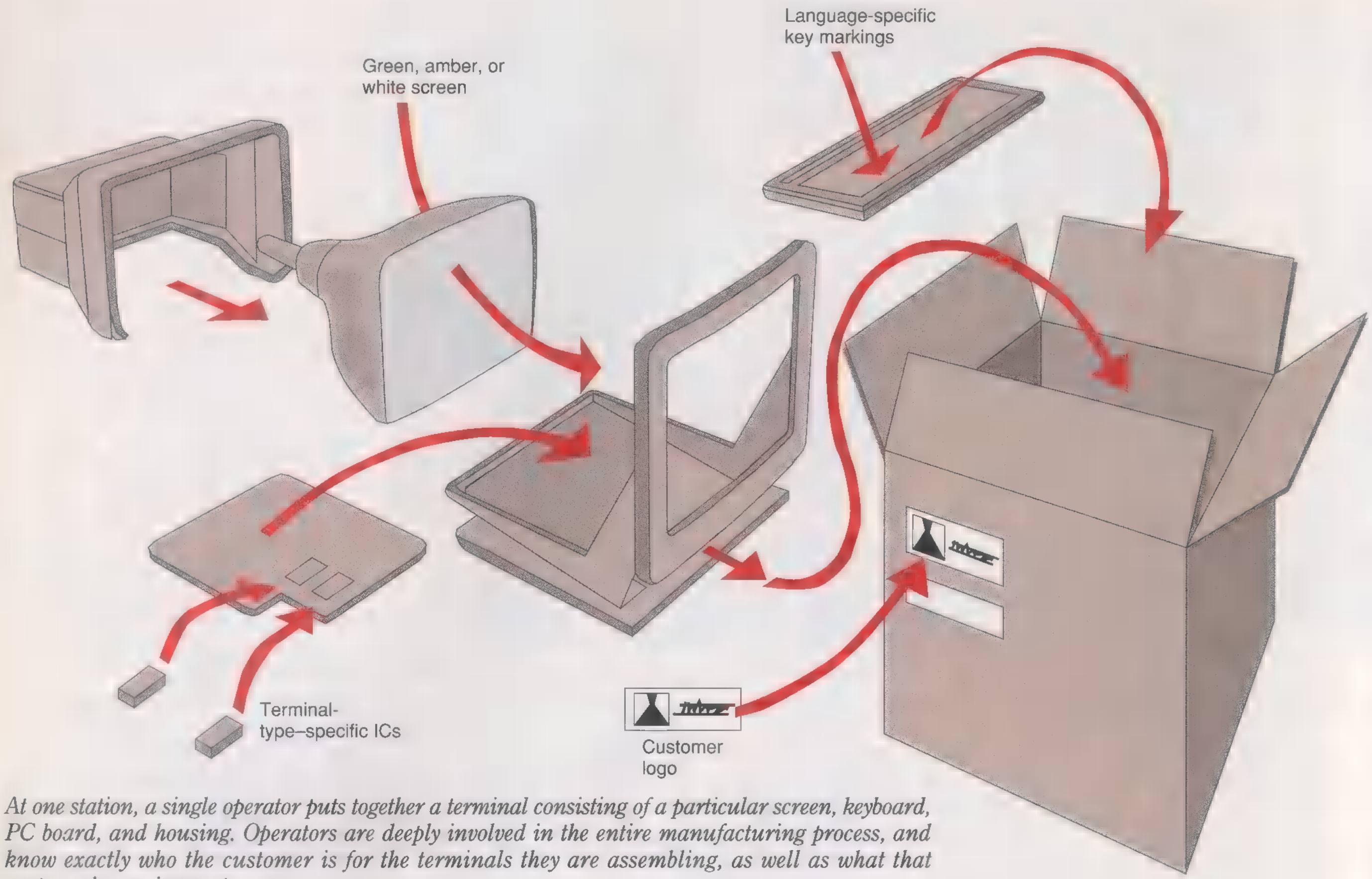
A key aspect of ADDS strategy in relocating to the United States was the development of a flexible, just-in-time (JIT) system with built-in quality assurance. Also crucial was the understanding that quality assurance required the best efforts possible from ADDS employees and suppliers. ADDS focused squarely on "as-built" quality, instead of results-based management, which does not always foster quality.

ADDS does not manage production by demanding that an operator produce X units per day. Instead, as an adherent of the teachings of W. Edwards Deming, ADDS designs ■ process that *allows* an operator to deliver ■ certain number of units per day. This approach focuses the production team's attention on solving the process problems that could keep the operator from achieving the desired level of productivity.

KEY FACTORS. JIT connotes the flow of parts into ■ factory just in time for use, as well as the manufacturing of goods just in time to fulfill the customer's needs. To succeed at this kind of manufacturing, an organization should consider three key factors: single-cell assembly, employee empowerment, and supplier relationships. Single-cell manufacturing enables a manufacturer to pump up shipments—up to fivefold with as little as 24 hours between receipt of order and delivery—by providing operators with the environment and the components they need to produce products quickly and efficiently. Empowering employees makes them contributors to the JIT flexible manufacturing process, as does establishing solid relationships with fewer but better suppliers and vendors. Such employee and supplier relationships are also vital to ensuring quality.

THE CELL CONCEPT. ADDS shipped more than 120 000 terminals in 1992, with an average 24 hours between receipt of an order and delivery. Yet it did not carry inventories of finished goods. This quick response is possible in almost any organization if it establishes ■ flexible manufacturing system based on single-cell assembly.

In single-cell assembly, ■ single operator assembles an entire product in his or her own assembly station, or work cell. All the materials needed to build ■ variety of product configurations are stored to hand



At one station, a single operator puts together a terminal consisting of a particular screen, keyboard, PC board, and housing. Operators are deeply involved in the entire manufacturing process, and know exactly who the customer is for the terminals they are assembling, as well as what that customer's requirements are.

at each individual assembly station.

In the ADDS case, the product is a videodisplay terminal (VDT) assembled by an individual operator under the guidance of a company-designed computer system. Customer orders are downloaded to the manufacturing system and are scheduled in terms of the customer's delivery needs.

With this system, a workforce of about 70 completes more VDTs each day than 330 people did formerly under a traditional setup. Now a worker can assemble a terminal in only 6 minutes owing to the factory's use of a system similar to *kanban*, the JIT approach developed by the Japanese. As applied by ADDS, the approach keeps the assembly station stocked with the inventory needed for the work in process, which is based on individual customer demand.

When production began in the cells, it became clear to the operators that some of the assembly required quite a bit of mechanical dexterity. The allegedly ergonomic industrial design lacked flat edges for resting the parts on the assembly surface. ADDS quickly learned that an empowered workforce paid off. To overcome this assembly problem, a team of workers got together—at home—and built special wood fixtures to hold parts during assembly.

After assembly, the terminals move to a geometry alignment station, where another worker adjusts the cathode-ray tube alignment, using a computer-controlled alignment system. Customized software collects data for the quality information system that guides ADDS and its suppliers in monitoring and adjusting the process.

From the earliest stage of the process on, clear instructions on the computer screen tell the operator not product part numbers, but exactly what is going to be built and for whom. In addition, the computer system does not allow the unit to go from Step 1 to Step 2, 3, 4, or 5 unless all necessary actions have been taken. This sharply reduces variability. An operator at any given station in the process has everything within arm's reach and at eye level. Every operation has a "jig," or fixture, to make it run smoothly, embracing a number of ingenious methods devised by the operators themselves.

Helping employees build more units is done by making the process simpler. The simpler it is, the less it can vary and the less that can go wrong. In addition, reducing the number of decisions the operator has to make speeds the process. Quality management and productivity drive each other.

MANAGING THE PROCESSES. With a properly designed manufacturing process, anything that helps the operator function within the system improves productivity, reduces product variability, and enhances his or her ability to excel at that process. These are the same factors that prevent a defective product from going out the door. Poor instructions, poor materials, and a lack of training impair productivity and result in a defective product into the bargain.

Soon after ADDS began its single-cell manufacturing, the company found that those who were performing final tests were returning 10–15 percent of the terminals. But if even one terminal was defective, productivity was hurt in terms of deliverable units to the customer. To solve this, ADDS had to overcome what used to be known as quality problems.

To this end, ADDS conducts a Pareto analysis at every stage of the process, to determine why an unsuccessful next stage of the manufacturing process is not successful. The company then examines these analyses and adjusts internal "customer" and supplier relationships as necessary. The goal is to keep the customer—in this case, the ADDS operator—satisfied. In this way, ADDS is driving productivity, and 100 percent quality is the net effect.

THE POWER TO IMPROVE. In view of the link between quality and productivity, any manufacturing organization should consider making real-time process yields and throughput information available to those who support as well as those who manage the process. ADDS's operators receive this information via display terminals in their work areas. ADDS also recommends that major customers be free to access the quality process information on their orders through on-line computer links.

To pin down what must be done to improve a process, the company established

a "mainline process yield." This is a total process number, which starts at the first stage of manufacturing and concludes when the customer accepts the unit.

What should the process yield objective be? As Deming pointed out, if management asks employees to give 99 percent, that is probably what they will set as their goal. Ask them to work with management to achieve 100 percent defect-free processes, and management is more likely to see its employees strive for 100 percent.

EVERYONE COUNTS. In any manufacturing process, many things, including the quality of poorly designed products, are not under the operators' control. It is important to give people full charge of their jobs by reducing the variability of external forces (like suppliers and process design). Management can do this by working with suppliers who agree with the JIT philosophy, instituting a well-designed system with careful controls, and establishing and maintaining a support infrastructure of people who understand the company's mission and the job that must be done.

Attendance is another good measure of productivity and quality management. The answer to the management question "How do I know if I'm doing a good job out there?" is "When my absenteeism goes down." Nothing frustrates people more than being ill-equipped to do their jobs, and the clear connection between stress and physical illness makes attendance a good measurement of employee satisfaction. An employee effectiveness survey based on the Baldrige criteria, such as the one ADDS uses, can monitor how employees rate management's efforts.

The object is to design a process that builds defect-free products that do not require checking or testing. Using the processes, methods, and philosophies described earlier in this article, ADDS has achieved a functionally defect-free rating above the 99 percent level. Moreover, this has become the minimum acceptable level among the company's operators because, as the process runs better, their expectations have risen. As a company eliminates the barriers to their success, assembly workers become less tolerant of any part, process, or person that stops them from delivering a top-quality product.

There is not a single point in the manufacturing and assembly process that cannot be influenced positively by operators. For example, ADDS's final-test operators redesigned their test stations to make them easier to use and more comfortable.

To be more specific, the operator at the final test station takes terminals off the conveyor and puts them on a vibration table. To test the unit, the operator must connect it to the computer and a keyboard. What complicates this seemingly simple task is the "flexible" in flexible manufacturing; there are a number of different port configurations and keyboards that customers can choose, and which the operators must test.

After working with the original test station design, the operators came up with some simple enhancements that improved productivity and operator comfort. The cables from the computer were put in a fixture that makes them easy to reach and plug into the rear of the unit under test. The keyboards and other necessary test equipment were placed in cubbyholes at the test station so that an operator can easily find, reach, and replace them. Finally, since the stations were fairly high above the floor (at conveyor height, not people height), foot rests were added for operator comfort.

Final testing is done for quality assurance, not to find faults that could have been prevented by proper manufacturing system design. However, one cause of failures may lie outside the factory, within the supplier base. Even if a company has excellent suppliers, there is a normal variation in product quality among them. This "normal" variation makes the overall variability in terms of input grow ever larger.

Working with suppliers whose processes are under control, and working with as few suppliers as possible, helps reduce the variability of input and ensure a stable input to the manufacturing process. ADDS reduced its supplier base dramatically, and continues to do so, by screening thoroughly for top-quality suppliers trained in JIT techniques. ADDS then instructs these suppliers in detail about its flexible manufacturing process.

THE RIGHT RESULTS. No matter what stage of the process a manufacturer improves, that improvement eventually will be reflected in a lower return rate. It is hard to imagine a TV manufacturer delivering TVs with a 3–5-percent annual field return rate: it would be out of business almost overnight. These same expectations have carried over into the computer terminal market: "My TV lasted five years. Why didn't my terminal?" When manufacturers drive quality by driving productivity, they can offer longer and more economical warranties and still make a profit on service.

Quality is all-inclusive, involving the entire process of producing a product. By focusing on every step of the process and examining both the qualitative and the quantitative aspects, manufacturers can improve product quality by improving the process itself. The results are satisified employees and, most important, satisfied customers. The development of a flexible manufacturing system is an exciting challenge. As the company strives to refine its flexible, JIT manufacturing process, no one has lost his or her job for making a mistake. After all, people who do not make mistakes will not be seeking new ways to succeed.

ABOUT THE AUTHOR. Vincent P. Luciano is director of product and market planning at the Displays Business Unit of Applied Digital Data Systems Inc. (ADDS), a division of NCR Corp. and AT&T Co. He oversees all product and strategic market programs and develops new market opportunities for ADDS. Luciano is also president and treasurer of the Display Industry Association, the independent consortium of hardware and software providers that developed and markets Alpha-Windows technology.

CASE STUDY
Allen-Bradley Co.

Growing an automated production line

Val Kukuljan Allen-Bradley Co.

The line on which Allen-Bradley Co. manufactures its World Contactor products has been in operation now for eight years. During that time, the factory's ability to produce different varieties of contactors has increased almost tenfold.

On the average, there are 76 parts for each type of contactor (a device for repeatedly establishing or interrupting a power circuit as part of normal system operation), and 22 of them are uniquely designed for a particular variation. Built into the line today is the ability to handle over 152 different parts.

The line itself—a flexible computer-integrated manufacturing facility known as Allen-Bradley's CIM line—operates to this day without problems, producing 600 contactors per hour. The initial investment of US $15 million in building the line has been handsomely returned, both in profits from the sale of the products it produces and by promoting the Allen-Bradley control systems that are key to its operation. Profitable utilization is foreseen for many years to come.

In the line's design and development, the methods used were chosen to eliminate major technical and functional design risks, as well as minimize estimated cost and schedule overruns. Thanks to a high level of system control flexibility, no direct human assistance is required for continued operation. The line, originally designed for 125 IEC (International Electrotechnical Commission)-contactor variations, currently produces 937 variations, with over 1000 projected. The changeover from one type of product to another is automatic and is completed within the 6-second cycle time of the line's machines.

Project implementation strengths included the full support of Allen-Bradley executive management, strong project leadership, and the assignment of engineering and skilled resources on the basis of talent and ability. They resulted in the selection of advanced technologies in the initial stages of CIM concept formulation. The approach built on a vision of the future that made this system, even by today's standards, an industry benchmark.

In the early 1980s, Allen-Bradley concluded that, competitively speaking, the timing was just right to introduce a new, worldwide product line based on the latest in technology and manufacturing methodology. The company established an executive objective of developing an automatic CIM system capable of producing both high quality and ■ variety of new contactors without direct human intervention. Thus 1982 marked the start of the development of a new world-class family of components: Bulletin 100-IEC contactors.

To succeed, it was felt that the project must take into account all the business needs of the factory that would contain the new manufacturing line. To this end, various groups (including finance, sales, marketing, product design, quality systems, purchasing, data processing, facilities, and operations) were asked for their input. The automated system was designed to meet both its own "factory" needs and those of the surrounding Allen-Bradley "factory." The inclusion of information systems yielded what would be known as the Factory in ■ Factory.

An effective technical team required a pool of qualified people for process optimization, machine design, material handling, and electrical controls. As it happens, Allen-Bradley has had a specialized department for designing and developing equipment and processes for internal use for over 50 years. Therefore, highly specialized and versatile resources with an in-depth knowledge of product and manufacturing methods were at hand. With such an organization in place, it was easy to transfer technology, as well as train operating and maintenance personnel.

DESIGN FOR ASSEMBLY. Once in place, the technical team began by considering all critical product development issues. The first step toward a final CIM specification was to formulate a design-for-assembly (DFA) requirement.

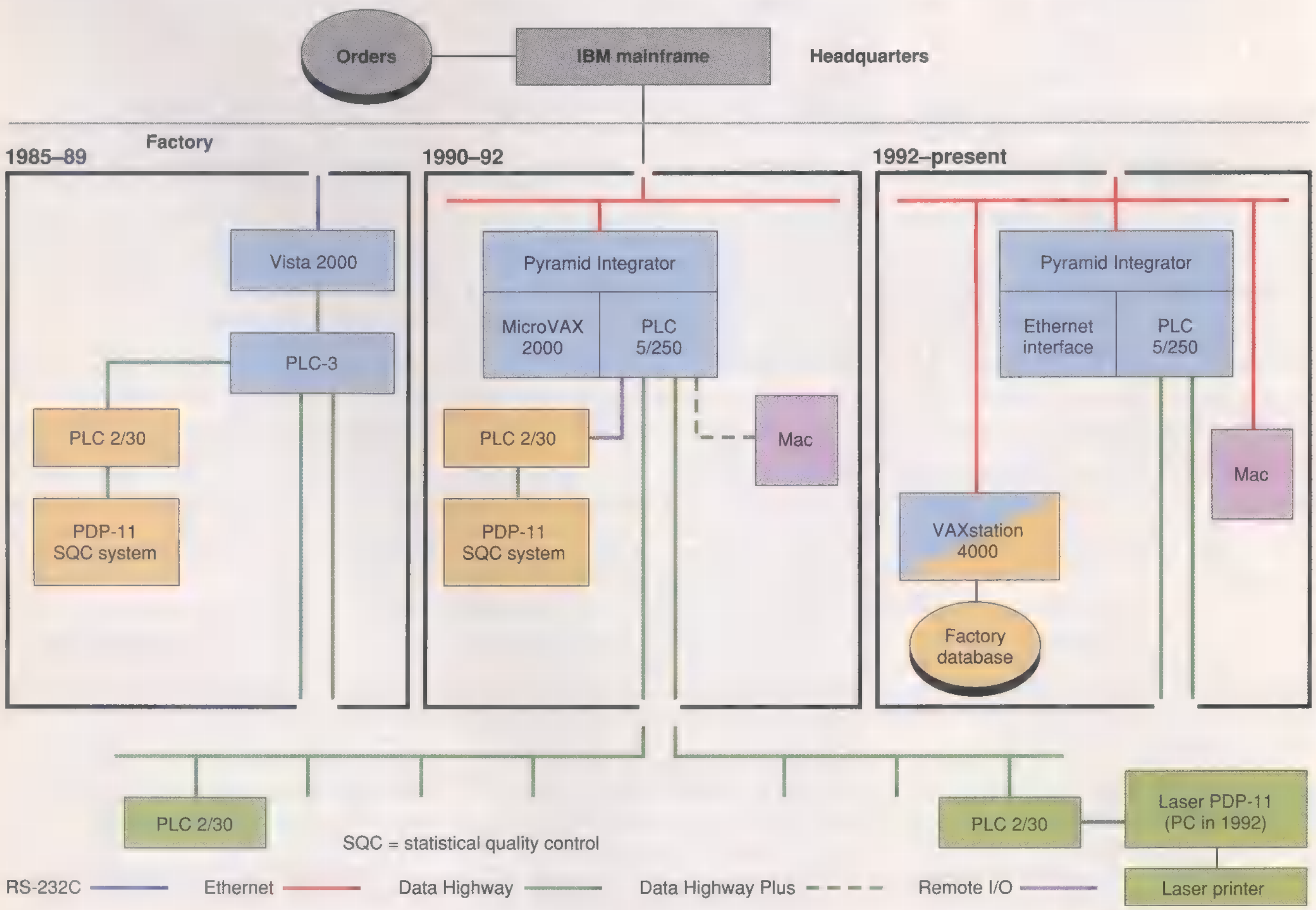
This involved reshaping some product components to fit an efficient new assembly process. It was obvious to experienced manufacturing personnel that a product designed for easy manual assembly would also be well suited to automatic handling. For instance, a key consideration was to eliminate the need to rotate, twist, or perform other complex motions in assembling the device.

At this point, the team ruled against using pallets to carry the products from station to station. Process optimization was an integral part of the product design. With a wide selection of modern materials, it was possible to simplify the fabrication and the feeding of parts, and no longer orient and vibro-drive them.

A pivotal part of process development was the application of laser markings. These accommodated numerous product variations, without frequent setup adjustments associated with ink printing. Instrumental in this application were bar code labels on the contactor's base, which therefore had to be redesigned. The bar code label introduces the contactor to each machine in line, and thereby requests a preprogrammed assembly sequence.

MATERIAL HANDLING. The next step was to develop an assembly process. A diagram of the complete material flow matrix was drawn again and again. The idea was to make it as simple as possible, with the fewest possible tangential paths, and well-balanced at each subassembly node. This task took the most creativity on the part of the people conceptualizing the system.

They had to visualize the assembly process complexity at each node, then adjust the matrix to balance the estimated assembly cycle time for each node in the entire system. In addition, although each node was a separate step in the assembly process, it was necessary to visualize a number of nodes being contained in each machine in order to optimize efficiency and reduce cost. In actual hardware, each node was thought of as an assembly station.



Changes in Allen-Bradley Co.'s contactor line over the last eight years have kept it productive. Note that PLC machine controllers and their Data Highway link did not change when engineers added new functions to the factory.

At this point, it was also possible to determine if any of the station assembly processes strained the available technology, and might need modeling to verify a practical design.

Thus, having defined the assembly process details and the material-handling needs, plus the standardization and aesthetics of the machine line, it was possible to define the composition of the system. The layout had to be fine-tuned to fit the machine line into a space perforated (so to speak) by many support columns.

The development of contemporary advanced systems was a balanced combination of electrical and mechanical functions. The electrical system requirements were developed as mechanical details became available. Thus the overall goal of utilizing modern technologies in a synchronous electromechanical design was realized.

CONTROL DEFINITION. The Factory in a Factory concept dictated the system control architecture. Each business area within Allen-Bradley provided its wish list, in terms of the input they could provide and the system output they would like. These wish lists were divided into "musts" and "wants," and then combined to define appropriate information systems.

Standardization of electrical controls and operator interfaces was a necessity at the machine level. The individual order quantity, the tracking of parts, and machine status (among other matters) defined the requirements of information systems within the facility.

For the type of assembly processes defined, a distributed system architecture was judged most appropriate. It also simplified the phased integration of the system during the debug and installation stages.

Development of the system's architecture took into consideration data acquisition, communications, and human interfaces; order processing and tracking; assembly-parts inventory control, quality information systems, and management reports; alarm handling, automatic start-up/shut-down, and preventive maintenance; and historical-data management.

The resultant system architecture is shown on the opposite page. The mainframe computer outside the facility electronically receives orders for IEC devices from district sales offices. It transmits the orders to the highest-level computer on the facility floor once every 24 hours. The main factory computer would pass the orders on to the supervisory controller PLC-3, and also handle all report output. The PLC-3 supervisor would schedule the orders and issue them one part at a time to the assembly line machines. It would also collect and dispense completed customer orders and prepare them for shipment.

SYSTEM UPGRADES. From 1985 to 1989, the architecture of the system remained basically the same, with the exception of the main factory computer. When Allen-Bradley introduced the Vista 2000 cell computer in 1987, it replaced a VAX 11/780 in the central control function.

In 1990, the very flexible Pyramid Integrator was introduced into the factory, replacing both the Vista 2000 computer and the PLC-3 supervisory controller. The high-speed backplane communication between the micro-VAX 2000 and the PLC 5/250 improved information system performance significantly.

At that time, an Ethernet communication network was installed between the Pyramid Integrator and the IBM mainframe computer, replacing the earlier RS-232 connection. As a local development project, a Data Highway Plus connection to a Macintosh computer was implemented. This architecture is shown on the 1990–92 section of the figure.

In 1992, the micro-VAX 2000 computer was replaced with a VAX 4000 station able to provide a full-fledged database function for the growing number of product variations. In the years since the facility began operation, new IEC product variations had been introduced. As noted earlier, the initial request was for 125 variations, and the original system was designed to handle 256. Currently, there are 937 varieties, and this number is expected to increase.

The memory requirements of the PLC 2/30s for each machine have been vastly increased by the additional product variations. To prevent a possible future overload, that portion of the distributed intelligence has been centralized in the new database. Currently, as a part enters the PLC 2/30 machine, it identifies itself via its bar code. The machine then requests processing instructions from the database. This occurs in real time, with no loss in system cycle rate.

The addition of an Ethernet communication capability at the Pyramid Integrator and VAX level in the architecture allows the interface to the system of Macintosh computers contained in most offices. Thus users can now easily create reports that best satisfy their own needs.

One more note: in the implementation of these major architectural changes, there was zero loss in production. Computer and control engineers programmed the new functions off line, then made the changeover with virtually no disruption. This speaks well not only for the engineers, but also for the controls whose compatibility allowed system expansion.

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CASE STUDY
Charles Stark Draper Laboratory Inc.

When people are too large and dirty

Daniel Whitney
The Charles Stark Draper Laboratory Inc.

What do inertial navigation instruments have in common with semiconductors, as well as camcorders, hard disk drives, cameras, and other precision electromechanical products? They are all characterized by relentless miniaturization, extreme precision, and such stringent manufacturing cleanliness requirements that there are serious doubts about the ability of human beings to assemble them.

Until recently, inertial instruments, such as gyroscopes and accelerometers, the key measuring devices in spacecraft and missiles, were assembled by highly trained technicians. But humans appear to be too large and dirty to assemble devices with tolerances measured in micrometers. Despite skill and dedication, those technicians could not keep failure rates at acceptably low levels.

The problem, in a word, was contamination. Particles scraped off the parts during assembly, as well as particles sloughed off or breathed out by the technicians themselves, seemed to be the culprits. Contact forces between parts of only a few millinewtons—and humans can barely tell when they are exerting forces that small—are enough to scrape tiny particles free. In addition, even when garbed in clean room "bunny suits," we still emit as many as 200 000 particles a minute into each cubic meter around us.

How precise and clean does a modern precision assembly have to be? In the case of inertial instruments, very clean indeed. The core moving part is a spinning wheel. To get the necessary accuracy, it is made to run on a gas bearing with a clearance of approximately 1.5 μm—a gap comparable to the line width of a typical semiconductor feature. Not surprisingly, contaminants less than a micrometer in size will destroy such an instrument just as surely as they will

Defining terms

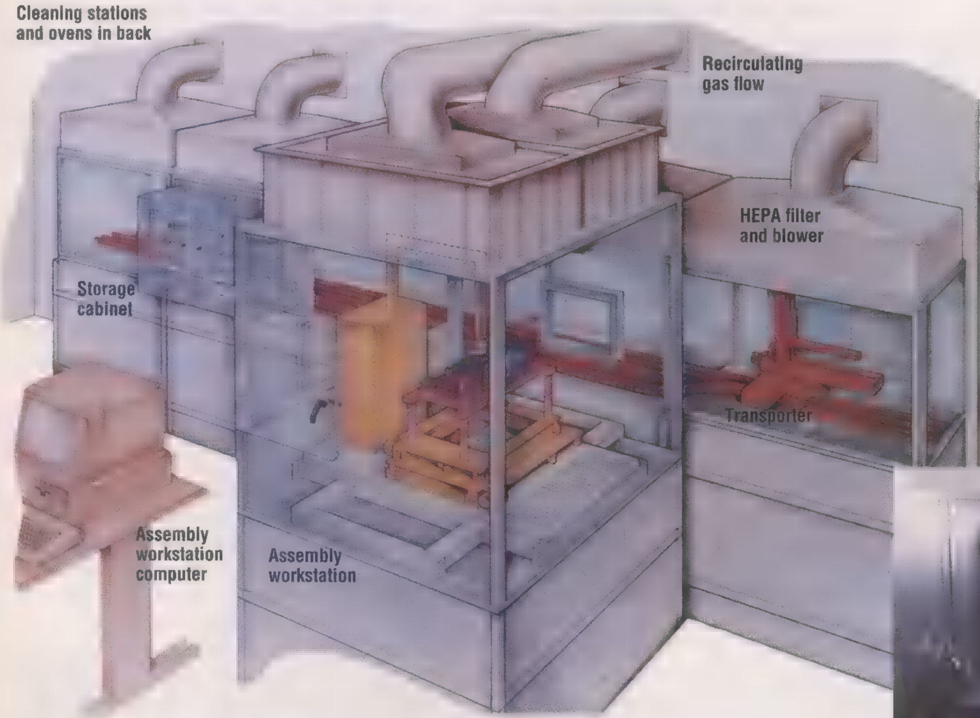
Ball slide: a linear ball bearing.
Hall-effect sensor: a sensor, based on the Hall effect, that reacts to small changes in a magnetic field.
LVDT: linear variable differential transformer, a differential transformer in which the inner core moves relative to the outer one, changing the coupling and permitting the detection of very small motions.
Outgas: using a vacuum to draw surface and subsurface gases and volatile components away from the parts.

destroy a microprocessor, a dynamic RAM, or any other semiconductor device.

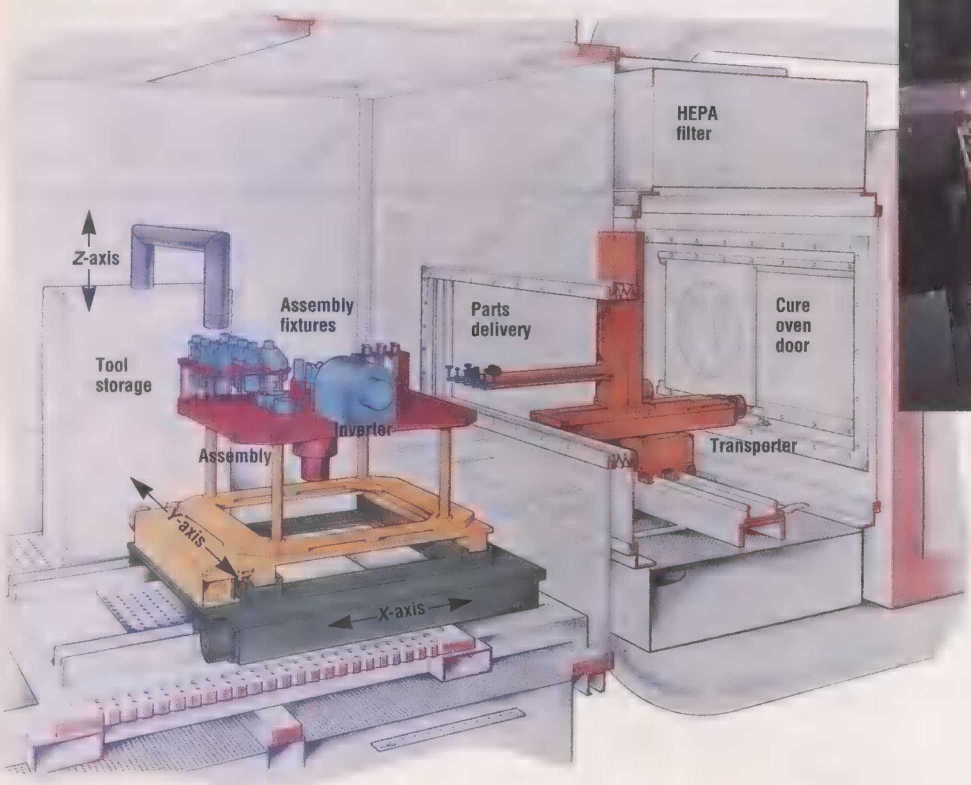
Semiconductor companies fight such problems by building extremely expensive plants in which contamination control is the largest capital expense after the process equipment itself. Products like inertial components, which are not produced in the huge volumes of semiconductors, require an automated solution that does not cost hundreds of millions of dollars.

Although there was serious doubt that mere humans were up to the job of assembling modern inertial instruments, there was no consensus that machines would do any better. True, they do not exhale, but the mechanical problems would certainly be formidable.

The job took a 15-year effort at Draper Laboratory, beginning in the 1970s with an investigation into the fundamental nature of mechanical parts assembly. That research generated highly engineered compliant (springy) robot wrists that permit close-clearance parts to be assembled with almost no contact force. These wrists, called remote-center compliances (RCCs), are the basis for the end-of-arm tooling in the machines that assemble inertial instruments today. The machines were designed on two basic principles: first, the use of automation for operations requiring the highest precision and the greatest freedom from con-



The sealed assembly system [upper left], which measures about 7 by 2 by 2 meters, contains a transport robot, two rinser-dryer stations, a vacuum bake oven, an epoxy-cure oven, and an airlock interface for inserting parts and removing finished assemblies. At its heart is a self-contained robotic assembly cell [lower left and photo] in which actual assembly takes place.



The key elements in the assembly cell are a three-axis tool-changing robot, a Y-axis stage for inverting the assembly partway through the process, and a base on which all the tools are stored and all work is done.

tamination and, second, the recognition of the need for ■ contamination-controlled process sequence that results in ■ sealed and tested unit.

In keeping with the first principle, the assembly system automated all material handling, cleaning, assembly, and test operations. The assembly equipment was designed with RCCs so compliant that they exert less force on the parts than people can detect with their fingers. Great care was taken to make the assembly equipment and tools from materials that would resist shedding particles.

Perhaps most important, the entire operation is enclosed in its own environment, in which different areas are isolated from one another. Inside that environment, the atmosphere is recirculated through high-efficiency particle-absorbing (HEPA) filters until Class 1 cleanliness has been achieved. (This means that there is no more than one particle larger than 0.5 μm per cubic foot of air in the environment.) The recirculation of internal air through HEPA filters permits the system to reach Class 1 within 15 minutes of being closed.

Recirculation is impossible with humans present. Makeup air with new oxygen for people to breathe carries new particulate contamination—the second-largest source of the problem after the people themselves.

No less important than the design of the assembly facility is the design of the assembly process. All the parts cleaning, verification, assembly, test, and sealing are performed in ■ wholly hands-off manner inside ■ single contamination-controlled environment, and the unit being built is not sealed until it passes the final test; only then is it removed from the cocoon. Some disk-drive manufacturers break these rules. They take sealed units from the clean room, test them outside, and then return failed units to the clean room, where disassembly and seal separation cause additional contamination and complicate rework.

SETTING SPECIFICATIONS. Before a facility could actually be designed, specifications had to be set for such parameters as contamination and assembly forces. Given the wheel's 1.5-μm clearance, it was decided that particles larger than 0.5 μm posed a potential threat to the instrument's performance and would have to be eliminated. It was decided as well that all parts would be mechanically cleaned and then outgassed in a vacuum oven before assembly.

Forces and torques, too, were studied and regulated by ■ verified process plan, which set limits that apply to various parts of the assembly process. The specification for assembly robot position repeatability was put at 25 μm. In some cases forces exerted on parts are limited to 100 millinewtons, and force-measuring resolution to an incredible 1 mN (0.1 gram-force). Routine force-measuring resolution is 9 mN. Torque sensitivity while parts are threaded together is 700 micronewton-meters. Sensors can detect adverse motions as small as 2.5 μm and 0.1 milliradian.

Of course, the system must be able to carry the parts to be assembled from the input section to each of the work areas, including the outgassing and epoxy-curing ovens, cleaning, assembly, and test. In addition, it must apply adhesives and perform several in-process tests. Finally, the entire facility was designed to run without human supervision, although operator intervention would be possible at any point. The machine was to be programmed and operated through ■ simple interface.

Unlike conventional factory automation, whose economic justification comes from balancing the investment against labor savings, this machine was justified by the increase in yield it would make possible.

TOTAL ENCLOSURE. The facility that resulted from these specifications is ■ totally enclosed flexible assembly system containing an input/output station to insert parts and remove completed assemblies, a four-axis material transport robot, two power-spray washing stations, an outgassing oven, an epoxy-cure oven, and an assembly cell. The assembly cell contains a tool-changing robot that can insert pegs in holes, screw parts together, and apply epoxy. All system sizing, tool complement, robot speed, and equipment operating times were verified by computer simulation to ensure adequate capacity for full production. Overall the system is about 7 meters long, 2 meters high, and 2 meters deep [upper left figure on opposite page].

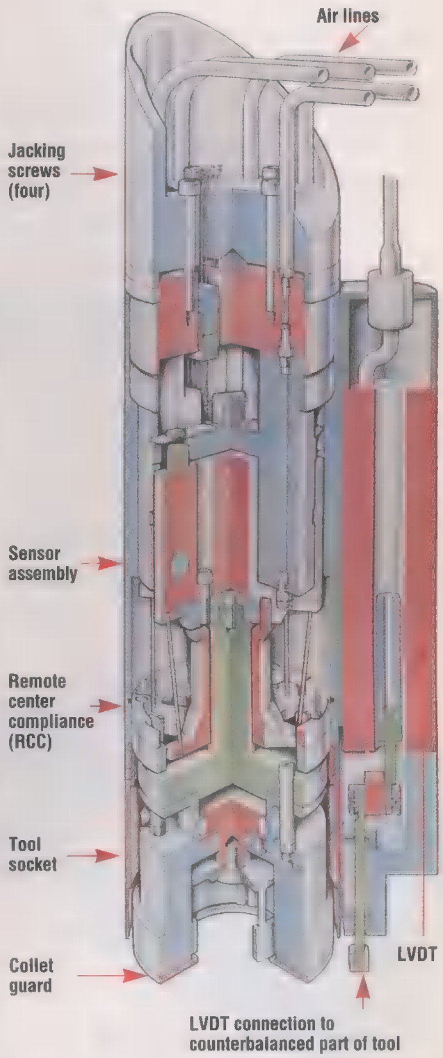
The system's heart is the self-contained robotic assembly cell, consisting of a three-axis tool-changing robot (X, Y, and Z axes), plus a Z-axis rotation for threading parts together and a Y-axis stage for inverting the assembly part way through the process [lower left and photo on p. 40]. The X and Y axes carry the base on which all the tools are stored and all work is done. The Z axis consists of a slender arm designed to interfere as little as possible with the laminar air downflow.

All pick and place assembly operations are performed by the tool-changing wrist at the end of the assembly robot's vertical arm. The wrist comprises three subassemblies: a tool socket where the tools that perform the actual assembly are inserted; a remote-center compliance, which accommodates lateral and angular misalignments from less than 1 μm up to 25 μm; and a sensor assembly used to monitor deflections of the RCC and the tool in all six degrees of freedom [see figure to right]. Key specifications of the wrist are given in the small table on p. 42.

The tool socket is the interface between the wrist and the tools used to pick and place parts and fixtures. A pneumatically driven draw collet secures and releases tools. By means of screw adjustments, the face of the tool socket is made parallel to the assembly base within 0.5 μm.

To determine its displacements relative to the arm in six dimensions—three linear and three angular—the RCC contains six Alnico VIII magnets and six Hall-effect sensors. These deflection sensors are particularly helpful for "teaching" the system to perform its delicate assembly tasks.

Teaching the machine means programming it, in an English-like language, with ■ sequential list of desired actions in terms of



Perhaps the most critical component in the system is this tool-changing wrist with its remote-center compliance for accommodating lateral and angular misalignments at the end of the assembly robot's vertical arm. The linear variable differential transformer (LVDT) serves as an extremely sensitive deflection sensor.

named parts, fixtures, and locations. In teach mode, the operator drives the machine's axes to the named locations, where the RCC sensors help align the parts. When they have been aligned, the operator stores the coordinate locations from the robot's X, Y, and Z axis encoders, establishing the coordinate values for the named locations. In further programming, these location names can be reused, so that it is not

necessary to drive the arm to previously taught positions.

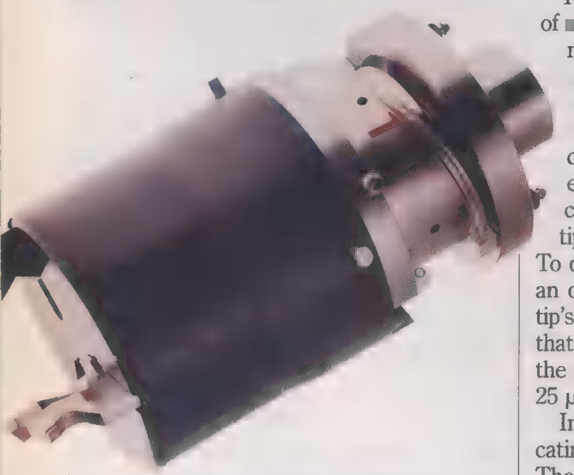
The tools have two main sections separated by a ball-slide and spring interface [see photo below]. The upper section, which mates to the tool socket, contains pneumatic interfaces to transmit air pressure for tool actuation. The lower section contains fingers that grasp parts and fixtures. The ball-slide keeps the tool vertical while the spring is set nearly to counterbalance its weight, permitting it to lift off at a very low vertical force and trigger the tool deflection sensor.

Mounted at the end of the wrist, that sensor, a linear variable differential transformer (LVDT), measures the vertical deflection of the counterbalanced lower part of each tool. Excessive vertical deflection, usually an indication that an assembly action is not proceeding normally, is detected very quickly. The height (or force) at which the sensor triggers action is programmable for each action and tool. If no tool is in the socket, the sensor acts as an inspection probe to measure the relative positions of critical subassemblies.

Tool-changing wrist specifications

Feature	Lateral, μm	Angular, mrad
Tool-changing repeatability	2.5	0.1
RCC and deflection sensor range	500	60
Deflection sensor sensitivity	2.5	0.1
RCC stiffness	3.46 N/mm	5.88 N•mm/mrad

RCC = remote-center compliance.



The upper section of the tool [tilted toward the right here] mates with the tool-changing wrist. The lower section, which is counterbalanced for high sensitivity to vertical forces, has fingers to grasp various parts and fixtures.

As a result of these design features, the system can assemble parts with very low forces, typically only a few dozen millinewtons. The tool design, which is particularly effective for screw-threading operations, could have been used to accommodate the advance of threads along the Z axis in two different ways: actively, by moving the tool and arm vertically at the correct rate as the threads advance, and passively, by first displacing the lower section of the tool upward (thus compressing the spring) at the start of threading, and then simply having the tool follow the threading downward. The second method was chosen, since it requires no programming or rate matching and guarantees that the applied force will not exceed a known maximum.

The tool's sensitivity to very small, unexpected upward forces permits it to detect errors quickly and thus prevent part damage. It is so sensitive that it has twice detected excessive assembly forces caused by contaminating particles thought to have been removed by thorough cleaning; in each case the offending particles were found later, and once they were removed, the assembly proceeded normally.

CLOSE CLEARANCES. For the most critical assembly operations, when clearances can get down to 50 μm, a special device called the high-compliance fixture comes into play. This fixture, containing a second RCC, is about 10 times more compliant than the RCC in the wrist. For enhanced sensitivity, its three Hall-effect deflection sensors use samarium-cobalt magnets.

The application of epoxy involves the use of a dedicated set of tools consisting of tiny needles and tubes attached to a dispensing device that measures out the epoxy in small drops whose size is computer-controlled for maximal precision. To ensure that the tip of the epoxy-dispensing needle is placed precisely, the assembly robot calibrates the tip's position just before epoxy is applied. To do so, the robot passes the tip through an optical detector and then updates the tip's location in robot wrist coordinates from that optical measurement. By these means, the needle's final placement is kept within 25 μm of the target position.

Individual trays fitted with accurate locating features deliver parts to the system. The transport robot carries the parts and trays to the outgassing oven and cleaning stations and then to the assembly cell. A clearance of 50 μm between the parts-holding pins and the parts permits cleaning liquids to reach all surfaces. The tips of the pins are coated with Kynar, a polymer that can be machined accurately.

COMPUTER CONTROL. Two microcomputers—an assembly workstation computer (AWC) and a transport workstation computer (TWC)—control the entire system. In various implementations, both IBM PCs and Macintosh IIfx computers have been used for those functions.

The AWC handles all assembly control, testing, sensor monitoring, and data storage and documentation. It controls the five axes of the assembly workstation with an indexing controller of the stepper-motor type and is connected to the other sensors and actuator hardware in the assembly cell through several analog and digital interfaces. The TWC operates the transporter robot, initiates and terminates the cycles of the two washing stations, and manages the interlocks between the transport robot and the doors on all the other cells.

A second indexing controller interfaces the TWC to the transport robot. Optical sensors at the end of its arm and axis motion limits are interfaced through the controller. Additional interfaces on the TWC monitor operate the doors, the cleaning stations, and the ovens.

To operate the system, an English-like programming language called DAPL (Draper Assembly Programming Language) was written in C. DAPL, which resembles numerical control and other robot programming languages, has such commands as MOVE, APPROACH <*named location*>, DEPART, ATTACH <*named tool*>, GRIP, and RELEASE. It operates in three modes. In manual mode, an operator enters commands through the keyboard. Entire assembly sequences can be put together as MOVEs, and tool operations are entered and their precise locations recorded with the aid of the sensors described above. This is similar to most robot teaching methods. In automatic mode, the assembly sequences run by themselves without operator intervention. In the semiautomatic mode, the steps can be called and run individually under operator supervision.

THEY REALLY WORK! So far, two of these assembly systems have been delivered to Department of Defense contractors, which are using them to make flight-quality instruments. Tests show not only that individual instruments built on these systems are more consistent over long periods of time than manually built ones, but also that differences between instruments are smaller. The improved consistency simplifies the substitution of one instrument for another.

This robot assembly technology is applicable to many products and processes. Although not cheap, the technology is not prohibitively expensive either. We estimate that the system we built could be duplicated for about US $800 000.

ACKNOWLEDGMENTS. The author was a member of the team that designed and built this system. The other members were Joseph Baxter, David D'Amore, Robert Fields, Benjamin Fudge, Todd Hamilton, Richard Metzinger, James Nevins, Reginald Roderick, Gregory Romano, Jonathan Rourke, Donald Seltzer, and Christopher Trainor.

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Making war on defects

In this world of faltering markets, competitive advantages are hard to come by. Still, one thing is clear: the quality of a company's product or service can determine success or failure.

Approaches to achieving quality vary, but the goals are similar. To most who concern themselves with this issue, quality means defect-free products and customers satisfied with services provided. It signifies the need to maintain tight control over manufacturing processes and to develop innovative (and inexpensive) methods for increasing design margins. It implies that manufacturability, testability, and the needs and wishes of the customer are kept in mind from the very beginning of the design process. And it demands that the quality products be designed and produced in the shortest possible time.

In this section, authors from Motorola Inc. and AT&T Co. discuss their companies' philosophies of product quality. The two philosophies appear to be quite different.

At Motorola, the focus is quantitative: quality is well-defined and measurable. Product reliability and performance requirements are rigidly defined and not subject to change—even when slated for internal customers. AT&T supports a style of management based on W. Edwards Deming's "fourteen points for management." It uses a four-step cycle of improvement and stresses employee education and empowerment.

Both companies have instituted aggressive methods for finding and eliminating sources of defects and for improving quality and turnaround time. Both have received Malcolm Baldrige National Quality Awards for their efforts.

Six-sigma design

Bill Smith Motorola Inc.

In January of 1987, Motorola Inc. abandoned its Top 10 Corporate Goals in favor of the singular fundamental objective of total customer satisfaction—the result of Motorola chairman Bob Galvin's conviction that "if you take care of the customer better than your competition, the business will take care of itself."

Quality is the linchpin in this strategy, since it largely determines whether the customer's expectations are met, particularly when taken in the context of the following definitions:

First, total customer satisfaction means more than satisfaction with the product; it is meeting or exceeding every requirement of every customer. It also includes technical support, billing, salesperson competence, product availability, and countless other interactions with the customer.

A failure to satisfy a customer, who is everyone from the next person in the process to the end-user, is a defect.

Defect-free performance in all products and services provided to the customer defines quality.

Quality performance is measured by total defects per unit (of finished product) throughout the process. It applies to both manufacturing and nonmanufacturing activities.

Reducing total defects per unit will not only reduce cycle time per unit, but will also result in fewer defects in the delivered products and fewer early-life failures. The net result is a better-satisfied customer, plus lower warranty and manufacturing costs per unit.

WHAT CUSTOMERS EXPECT. Given that end-customers buy a product because they perceive its cost/performance to be fair value, they expect it to do the following:

- To be delivered when they want it, meaning that the manufacture and distribution process must have a very predictable and short cycle time from receipt of order to delivery of the product.
- To work "out of the box," meaning "plug in and play" for most products. For those products that require installation, the instructions must be clear and simple, and the process of setup must be proofed against mistakes.
- To exhibit no "infant mortality." Customers judge the reliability of the product early on in its life. They do not defer judgment until the product is retired from service.
- To be reliable in use and capable of the swiftest repair even though failures may be rare.

On-time delivery is a function of the average cycle time per unit. Cycle time in turn is proportional to the number of defects per unit within the entire process, since every defect must be diagnosed and repaired.

Defects in the delivered product are due to imperfect test and inspection processes. No test or inspection is ideal. Tests have shown that visual inspection is no more than 80 percent effective, and then only in structured tasks in which a set of prescribed checks is administered repeatedly. Yet some companies still believe the only way to deliver a higher-quality product to the customer is through more test, more inspection, or more screening. Not only is this ineffective, it adds significantly to product cost. The average number of delivered defects is directly proportional to the total number of defects found within the entire manufacturing process.

Infant mortality is due to latent defects. These are abnormal characteristics of the product that cause it to fail early in its life as it encounters the stress of actual use. In general, a product's probable time to failure decreases with both the degree of abnormality and the amount of stress applied. Studies have shown a direct correlation between the average latent defect content per unit and the total number of defects per

Defining terms

Capability index (C_p): the ratio of the design specification width to the normal variation. C_{pk} is a capability index that factors in the batch-to-batch variation of the mean from the design value.

Concurrent engineering: simultaneous vs. serial activity in all phases of the design and manufacture of a product.

Cycle time: the sum of the start-to-finish times of a number of predetermined events.

Design specification width: the acceptable range of variation of a parameter in a design.

Flexible manufacturing system: a process in which each value-added step can be working on a different product.

Infant mortality: early-life failures relative to the useful life of the product.

Key characteristic: one that determines the acceptability of the end product to the user.

Latent defect: any abnormal feature or component of a product that causes early failure due to the normal stress of use.

Mean time to failure: the expected or long-term average time during which a unit is expected to perform in a satisfactory manner.

Normal variation: plus or minus three standard deviations.

Robust design: one in which the capability index is greater than two.

Total defects per unit (TDU): the sum of the defective parts per million of all key characteristics, all components, and all process steps.

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unit (TDU) within the entire manufacturing process.

An understanding of the above relationships yields two conclusions. First, a product is built in the shortest time and at the lowest cost if no mistake is made in the process. Second, if no defect can be found anywhere in the process of building a product for the customer, then the customer probably will not find one either.

As for long-term reliability, the greater the design margin (the more robust the design), the lower the inherent failure rate. A robust design is better able to withstand the stress of use without failing.

It is also true that the more robust the design, the lower the TDU in the manufacturing process. Thus, the key to increased customer satisfaction at lower cost is design that is robust in use, in the environment of use, and in the process of production. The primary measure of robustness is the capability index (C_p), defined as the ratio of the maximum allowable range of a characteristic to normal ±3 sigma variation. Product designs that have high C_p for all key characteristics are not only extremely reliable in service, but also exhibit very low TDU in manufacturing.

Traditional good design practice required designs in which the tolerance limits of a characteristic were set at ±3 sigma ($C_p = 1$). This will result in a minimum of 2700 PPM (Motorola's term for defective parts per million) for that characteristic, or at least 27 defects per unit for a product containing 10 000 characteristics. Obviously, 3-sigma product designs come nowhere near the fewest possible defects per unit.

Beginning in 1987, Motorola designers were required to adopt ± 6-sigma tolerance limits ($Cp = 2$), given that the standard deviations were those of a world-class process. In simple terms, product design margins were to be twice the normal variation of the process. At the same time, it was recognized that it is not always possible to maintain a perfectly centered process. In those cases where direct feedback control can be employed, output can be maintained very close to the target design value, with little variation. Many processes, however, do not lend themselves to direct feedback techniques.

For example, the dimensions of molded plastic parts cannot be controlled while the parts are still in the mold. They must be removed from the mold and allowed to cool. In cooling they will shrink, perhaps 15 percent. So a sample is taken, the average dimension measured, and if it is too far off target, the process is readjusted. This is indirect process control, and in such processes, batch-to-batch variation can be as much as ±1.5 sigma off target. With a perfectly centered process, the defect rate of a 6-sigma design is 2 parts per billion, but for the shifted process the defect rate is 3.4 parts per million. This is the reason that Motorola equates its 6-sigma process to 3.4 PPM. [See "The significance of sigma," p. 46.]

The percentage of product going through the entire process without touch-up or repair is a function of both robustness of design and product complexity. Given a ±1.5-sigma shift, it becomes obvious that designs having less than ±6-sigma capability are incapable of being consistently produced with high overall yield [see table, p. 45].

CONCURRENT MANDATE. Total defects per unit are determined by summing the defective parts per million of all key characteristics (those that determine the acceptability of the end product), all components, and all process steps. A significant portion of TDU is contributed by the key characteristics. They are what control customer satisfaction with the end product.

The higher the capability index for a key characteristic, the lower the PPM for that characteristic. Clearly, C_p increases with the design margins, which are controlled by the product design, and it decreases with the width of the parameter distribution, which is controlled by the design and execution of the process. Consequently, an extremely effective way to achieve high C_p is through joint and concurrent design of the product and the process. In other words, products of high quality, high reliability, and low cost can be achieved through simultaneous or concurrent engineering.

THE CONTRACT BOOK. Being first to market with a new product is strategically important, particularly in the high-technology arena. Formerly, product development cycle time was defined as the time from conception of the product until the product was released to manufacturing. The new definition includes the time from conception until the product is being manufactured at the quality level required to totally satisfy the customer.

In the past, the time it took to develop a new product was inordinately long, in large part because engineers wanted to incorporate the latest and greatest technology in their new product designs. But the fact that the latest technology was announced every Monday morning meant designing to a constantly moving target. One reason was the lack of a set of firm end-product definitions, such as those found in a customer contract. Another was the habit of "throwing the prototypes over the wall" to manufacturing. In this scenario, initial production quality was so poor that months, and sometimes years, were needed for the factory to reach the required quality levels.

An end to lengthy development time was found in the creation of a "contract book" for all in-house product development. When the same stringent requirements were placed on the organization as when it was under a development contract with a large outside customer, the development process firmed up dramatically. Setting a highly specific set of unchangeable deliverables, plus rigid quality and reliability goals, slashed the total cycle time.

The quality goal for every new product is to achieve a lower TDU in first production than the product it will replace, for this is the only way that customers will see higher quality and that manufacturing costs will be reduced.

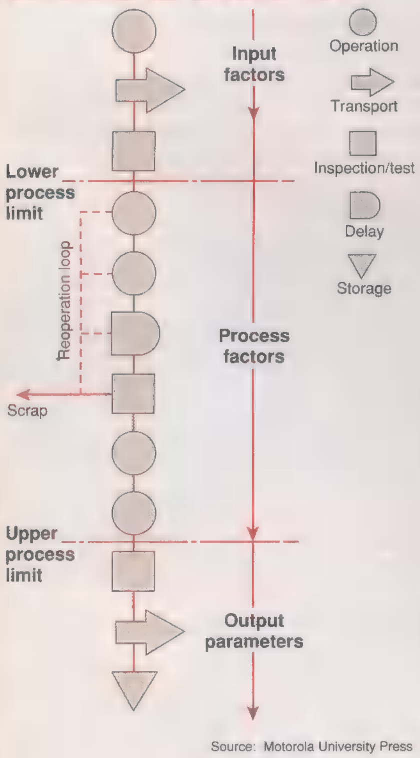
For organizations that are measuring TDU for all currently manufactured products, a baseline already exists for the improvement goal. In some cases, the new product will not replace an existing one, so the baseline used will belong to a currently produced product of similar physical and functional complexity.

In a few instances, the new product far surpasses any existing product in physical and functional complexity. Then a numerical estimate of complexity must be calculated by comparing it with products already being manufactured.

SIX-STEP PROCESS. In Motorola's Design for Manufacturability, a two-day course taught to all engineers during the last eight months of 1987, a six-step process for new product design was prescribed:

• Determine the physical and functional characteristics of the product necessary to

Delimiting the process flow



The ultimate quality of a product depends on the capabilities of the manufacturing processes as well as on a clever design. To ensure that a process meets the capability requirements, the first step is to define its limits—where it begins and where it ends—identify its individual steps, and establish all known independent parameters. Those steps that contribute most to the final quality can be identified and a strategy for achieving 6-sigma control can be developed.

Yield versus product robustness and complexity

Complexity: parts/product	Yield, percent			
1	93.54	99.3	99.9	100.0
3	81.84	98.1	99.9	100.0
10	51.27	93.9	99.7	100.0
30	13.48	83.0	99.3	99.9
100	0.13	53.7	97.7	99.9
300	0.00	15.5	93.2	99.9
1000	0.00	0.2	79.2	99.6
3000	0.00	0.0	49.7	98.9
10 000	0.00	0.0	9.7	96.6
30 000	0.00	0.0	0.09	90.3
Robustness				
Std. deviations	$\pm3\ \sigma$	$\pm4\ \sigma$	$\pm5\ \sigma$	$\pm6\ \sigma$
C_p	1.00	1.33	1.67	2.00
C_{pk}	0.50	0.83	1.10	1.50
PPM	66 810	6210	233	3.40

C_p = capability index, the ratio of the design specification width to the normal variation of the process.
C_{pk} = mean-shifted capability index. PPM=defective parts per million.

Yields vary for products with differing design margins and complexities. For a 6-sigma design, C_p is 2; C_{pk} of 1.5 allows for batch-to-batch mean variation of ±1.5 sigma. At all design margins, product yield decreases with complexity. For 3-sigma designs, yields are effectively zero for products with more than 100 parts. On the other hand, 6-sigma designs still have acceptable yields even for products with over 30 000 parts.

satisfy the customer.

- Identify the key characteristics of the design that control the end-product requirements.
- Identify the process controlling each key characteristic.
- Determine the target value and the allowable variation for each key characteristic.
- Determine the capability index of the process used for each key characteristic.
- If the capability index (C_p) is less than 2, seek design or process alternatives.

When engineers were exposed to the six-step process, their first reaction was to say, "If we have to do this on top of what we already do, it will take longer to design the product." In fact, the use of the six-step process in conjunction with the requirements of the contract book shortened design cycle times significantly.

The method provides a structured design process that quantifies the producibility of the design long before first production. Thus, the closer one gets to production, the fewer the surprises.

MANAGING THE DESIGN PROCESS. Designing a product to achieve an initial production quality goal with an aggressive TDU changes the focus in managing the design project. An initial defect-per-unit budget is established, based on the target value in the contract book.

In the early phase of a design, little may be known of the design details, other than that the product may consist of, say, seven major modules. Initially, the defect-per-unit goal may be equally apportioned over all modules. If, as the actual design takes shape, it becomes evident that some modules are much more complex than others, the project manager can then reapportion the defects-per-unit by taking some away from the less complex modules, and giving them to those that are more complex. In all cases, the total TDU of the product is unchanged.

At every design review, the TDU estimate for the current state of the design is also reviewed. Design alternatives are required for any module for which the estimate exceeds its budgeted goal. Each of the key characteristics is identified, and both the C_p and PPM are calculated from numerical inputs obtained from both the design and manufacturing areas. Absence of a known design margin indicates that further design simulation is needed. Absence of a known process variation means that more process capability studies should be done by manufacturing.

In attempting to hit a TDU design goal, the project team addresses three factors: reducing the number of parts, simplifying the manufacturing process by using fewer steps, and simplifying the design by minimizing the number of key characteristics.

This new approach has also forced a dramatic transformation from the old "unilateral" tolerances to specifications that are statistically sound. As an example, compare the old and new methods of designing a shaft to fit in a hole. For a shaft diameter of 1.000 cm, the upper and lower design limits usually were 0.000 cm and −0.005 cm, respectively; for the 1-cm hole diameter, the upper and lower design margin limits were +0.005 cm and 0.000 cm respectively. With the new method, however, the specifications are set at 0.9975±0.0025 cm for the shaft diameter and 1.0025±0.0025 cm for the hole diameter.

In the old scheme, from the designer's point of view, the shaft could be allowed a smaller diameter than nominal, but not a larger one, with the converse true for the hole. In the new scheme, engineering and production are in agreement. The only thing left to do is to determine the capability of turning the shaft and of boring the hole. If the turning operation has half the variation of the boring process, then the ratio of the tolerances is adjusted so that the shaft is allowed half the tolerance of the hole. In the unilateral tolerance world, such differing capabilities are not usually considered.

MISTAKE-PROOFING. Achieving the target TDU goal in manufacturing requires not only that all key characteristics have a C_p of two or greater, but also that the assembly operations be mistake-proofed. Concentrating on a high C_p alone might result in designs that are prone to erroneous assembly. An example of this is given in the case of the electronic ballast.

The TDU estimate can be calculated only if the PPM value for each key characteristic is established. For each of these characteristics, the product designer must determine the true tolerance while manufacturing must specify the normal variation of the process. In this way, the requirements of concurrent engineering are reinforced throughout the design project.

Obviously this technique must be extended to supplier-furnished components as well. So suppliers are involved early in the new product design, often to the point of actually designing the part to be furnished.

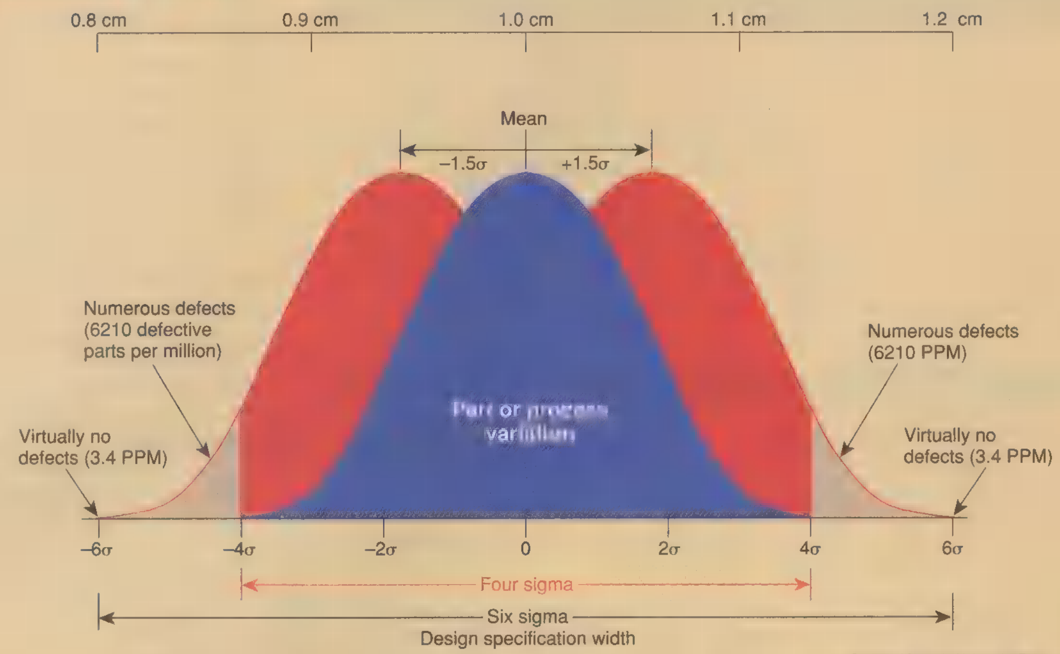
The following two examples show how the principles of 6-sigma design helped different electronic products achieve their production goals.

PIONEERING BANDIT. A new pager, code-named Bandit, was one of Motorola's first designs to apply the new principles of enhanced robustness. The goal was an integrated product and process design that would achieve a minimum 5-sigma quality level at first production, using a fully automated flexible manufacturing system with a lot size of one.

One hurdle was finding a robot with an acceptably low defect rate. But the most capable robot to be found on the market proved to exceed the defect rates required. The supplier agreed to redesign the robot and did so three times over the 18-month span of the project. Finally a version was provided that kept defect rates as low as required in all spatial dimensions and sigma.

Process capability data was diligently collected from the chosen suppliers, and in many cases, component specifications were rewritten to match the true tolerance required by the design with the process capability of the supplier. The pager's molded

The significance of sigma



Source: Motorola University Press

Though the manufactured parts in any one batch may be nominally the same, there is always some variation in their measured characteristics. For example, if 1000 rods 1 cm in diameter are made, their measured diameters will differ slightly. The distribution of measured diameters will fall along a curve like the one above. The top horizontal axis of the figure above shows the measured diameter in centimeters; the bottom axis is expressed in standard deviations. This so-called normal curve is representative of many processes. In such distributions, the number of parts having any measured diameter decreases the farther that value is from the mean. The center curve above represents a case for which the mean equals the design value of 1 cm.

A characteristic of normal distributions is the standard deviation, or sigma. In these curves, 68 percent of units (or events) fall within plus or minus one standard deviation (±1 sigma). The standard deviation—which in this example is 0.033 cm—indicates the breadth of the distribution. A more tightly controlled process would have a smaller standard deviation. One way typically used to improve yields is to reduce sigma by using more precise tools and operations.

Another way to improve yield is to increase the design specification width. This influences the quality of the product as much as the control of process variation does. In the case of the 1-cm rods, a design that works even if the rod diameter is off ±0.2 cm clearly results in fewer defective products than one that allows only a ±0.1 cm variation. The specified width can also be expressed in standard deviations, and here, a design specification width of ±0.2 cm corresponds to a ±6-sigma design.

The importance of both design specification width and process variation to overall quality is reflected in the capability index, C_p—the ratio of these two quantities. The wider the design specification width and the narrower the process variation, the greater is C_p and the larger is the number of defect-free units.

In some manufacturing processes, the mean varies over time, or from batch to batch. A variation of as much as ±1.5 sigma is not surprising, especially in processes that are under indirect control. Naturally, this increases the probability of finding units farther from the design value and the yields go down. The two outer curves in example above show what happens when the mean shifts by 1.5 sigma from the design center.

A second capability index, C_{pk}, tracks the batch-to-batch shift of the mean. C_{pk} is proportional to C_p, but also depends on the amount by which the mean varies from the design value. A 6-sigma design with no drift of the mean would have a C_p and C_{pk} equal to 2. If the mean drifts by 1.5 sigma, C_p remains 2, but C_{pk} is only 1.5.

A component with a design specification width of ±4 sigma, manufactured in a process with a mean variation of ±1.5 sigma, would result in 6210 defective parts per million (less than 1 percent), while a ±6-sigma design would produce only 3.4 parts per million defective. On the face of it, these are both small numbers. But the yield of a product also depends on its complexity, and rapidly drops off with the number of parts or process steps required. For a simple case in which a product is formed from a number of parts all having the same yield, the probability that a unit of product is defect free depends exponentially on the number of parts. The result is that a product composed of 1000 parts designed with a specification width of ±4 sigma has in effect a yield of zero, while the yield of one designed to ±6 sigma would still be almost 100 percent.

—Linda Geppert

plastic case was in fact designed by the supplier, and the result was of far higher quality than in the past.

The net outcome of this project was to achieve the quality targeted for first production. Pilot production began within one week of the goal that had been set 18 months earlier. The approximate 42 days from receipt of order to delivery of product for the previous generation was reduced to about 70 minutes. Return rates for first production units were in the tens of parts per million, with a new policy of guaranteed 24-hour replacement in the first six months of use.

Mistake-proofing the design is an essential factor in achieving the TDU goal. The design team is forced to investigate any opportunities for errors during manufacture and assembly, and to eliminate them. This occurs early enough in the design so that the costs are virtually nil, as the next example shows.

ELECTRONIC BALLAST. An electronic ballast for fluorescent lighting has many advantages. It provides flicker-free light. If one tube fails in a set of four, the other three are unaffected. But most important, it consumes about 40 percent less power than a conventional ballast for the same light output. Although a conventional iron ballast is less expensive, its most serious disadvantage is that its failure rate is wretched, averaging nearly 1.5 percent per year.

Motorola elected to enter this market, and set a quality goal of 6 sigma for initial delivery. This required a very strict TDU budget. But it became evident early in the project that achieving a C_p greater than 2 would go only part of the way. Mistake-proofing the design would also be required.

The mounting of the five iron components on the circuit board invited

mistakes in the assembly. All five looked much the same to an operator. So how could the designer ensure that a part would not be mounted in the wrong place? The solution was to use ■ distinctive mounting footprint for each. It was then impossible for an operator not to mount the part in the right place. This action absolutely precluded ■ wrong-part defect and cost almost nothing.

WHAT PRICE QUALITY? Most people can see that a product *manufactured* with the fewest possible defects per unit will boast high quality at low cost. But they believe that to *design* a product for that quality level will be very expensive.

Experience has proven this belief to be false. When a project is managed to achieve the targeted TDU at first production, and the goal is taken into account at the outset, then design alternatives can be selected very early in the project at minimal cost. Designing the product, and then waiting until the pilot run to find out the quality, as in the old method, is what drives up the costs.

It is also true that the ability to make revolutionary improvements is only practicable when the design is still on paper. Once ■ product goes into production, improvements become evolutionary.

ABOUT THE AUTHOR. On July 3, 1993, shortly after submitting this article, Bill Smith died unexpectedly.

Bill Smith was vice president and senior quality assurance manager for Motorola's Land Mobile Products Sector, in Schaumburg, IL. He was a Registered Professional Engineer in Quality Engineering and a Motorola Science Advisory Board Associate. Motorola's CEO Quality Award was only one of many awards he won for his work in quality management.

The principles that he presents in this paper became the fundamentals of Motorola's Six Sigma quality crusade, which over the past six years has reduced the cost of quality per unit shipped by 80 percent. The cumulative manufacturing cost savings have exceeded US $4 billion, and employee productivity has doubled.

According to Richard C. Buetow, senior vice president and Motorola director of quality, Bill Smith's wisdom and insight will be missed by Motorolans and by the literally hundreds of companies with which he has shared these principles over the last six years.

Total Quality Management

Joseph Bellefeuille   AT&T Network Systems

Many companies around the world are feeling "squeezed" by the birth of a global economy. Those engaged in electrotechnology manufacturing are no exception. As industries once dominated by U.S. and European companies crumble one by one and move offshore, business leaders are realizing that something has to be done. The initial reaction was to throw up trade barriers. Since this did not succeed, organizations are turning inward.

This time such slogans as "zero defects" and "do it right the first time" will not work. Nor will the seemingly logical systematic approaches: when one's competitor is in nonstop pursuit of improvement, an occasional improvement in something that isn't working (management by exception) or improvement efforts that are spread too thin (management by objectives) simply cannot keep up.

So what must management do? The answer has become Total Quality Management (TQM). Interest in TQM began to gain momentum in the West when NBC aired a white paper documentary in 1980. This broadcast featured an American named W. Edwards Deming. His now famous "fourteen points for management," when followed, appear to move organizations toward prosperity.

The goal of TQM is to create ■ system of management procedures that focuses on customer satisfaction and transforms the corporate culture so as to guarantee continual improvement. Simply stated: Total Quality Management is an interlocking arrangement of procedures and practices that ensures that all employees in every department are adequately trained and directed to continuously implement aligned improvements in quality, service, and total cost such that customer expectations are met or exceeded.

TQM focuses on three critical elements: customer expectations, full participation, and continuous improvement.

Every operation in a company has to be on the customers' behalf, or it is wasted effort. Robert Allen, chairman and chief executive officer of AT&T Co., has stated that his vision for the 1990s is the customer saying, "That's a company really interested in helping me solve problems and improve my business...." This type of vision is central to the TQM philosophy.

Customer surveys, customer focus groups, customer complaint analysis, and more, are all tools for understanding their expectations. The Cadillac Division of General Motors actually has customers sit in seat mock-ups to get their reaction before the design is finalized. A service company uses clients to design new services and to train their customer-contact personnel.

To satisfy the customer consistently, a company must rely on well-designed processes and procedures that work better than before every time. One of the guiding principles of TQM is that nobody understands the process and its shortcomings better than the person working with it. To render TQM operational, organizations involve absolutely everyone. Consequently, every job has two equally important parts. One part is to deliver the product or service. The other is to improve the way the products or services are delivered. But almost all jobs involve more than one employee—indeed, usually several, linked by closely related process steps. This situation gives rise to teams of employees investigating ways to improve the process.

TQM teams adopt a scientific approach to problem solving. The Japanese dub this the Deming Cycle. Deming himself calls it the Shewhart Cycle, after Walter Shewhart, a Bell Laboratories scientist, whose work in the 1920s and '30s led to modern statistical process control.

The improvement cycle has four steps; namely, plan for improvement, do what was planned, check if the results were as expected, and take appropriate action. Hence, it is sometimes called the plan, do, check, act (PDCA) cycle of improvement.

Defining terms

Circuit pack: a subsystem, or functional part of a system, consisting of a bare printed-wiring board and assembled components, sometimes referred to as circuit card or printed wiring board.

Continuous improvement: a system in which individuals in an organization seek ways to do things better, usually based on control of variation.

External customer: the ultimate user of a product or service; usually the person who pays for the product or service.

Facilitator: a person who coaches the team on process. The primary focus is on the leader to make sure that everyone gets an input.

Internal customer: the person(s) working next in the process.

Management by exception: a strategy whereby the manager focuses his or her attention on malfunctioning methods and procedures; it allows total concentration in trouble areas.

Management by objectives: a methodology constructed around the idea that an organization's top executives set its direction by generating objectives for the next lower level in the hierarchy. This process is repeated down through all levels of the organization.

Quality Planning Matrix (QPM): a document that contains a list of the policy for the plan year it is distributed to all employees at all levels in the organization, so that they can align their efforts better.

Policy deployment: translation of Japanese of *hoshin kanri* (planning). It orchestrates continuous improvement in a way that fosters individual initiative consistent with the goals of the corporation.

Standardization: the system of documenting and updating procedures to ensure that all process workers are clear about what is expected of them,

Statistical Process Control (SPC): the use of knowledge and insights based on statistics to maintain and improve processes.

While the analysis so far provides insights into three key aspects of TQM, it fails to convey the power of the approach because it does not consider the interactions of the components. Any system of components, whether an automobile, a rocket ship, or a management system, is characterized not by its parts but by its overall performance—the result of the interaction of the functional components. But given the goal of satisfying the customer in a world market that is in a high state of flux, the interactions are dynamic and the measurements are ever changing.

ENACTING THE DEFINITION. In the United States, the criteria of the Malcolm Baldrige National Quality Award (MBNQA) provide a framework for understanding the interactions among the vital components of TQM, as well as a systematic way of measuring the intrinsic quality of an organization. The criteria require that the external focus as well as internal quality measures are based on customer satisfaction. Others are that the systems for delivering products and services as well as human resource systems be dynamically geared to customer satisfaction, and that there be evidence that improvement is systematic and ongoing.

In this environment of interaction and teamwork, "no man is an island." This departs a long way from the philosophy advocated by Frederick W. Taylor at the start of this century. Taylor taught that procedures could be improved by specialists telling the worker what to do and how. This "check your brains at the door" approach suited an era when the labor force was fresh off the farm; but it has remained intact for most of the 20th century. Thus, the engineer is seen as a specialist, expert in carrying out analyses and computer simulations and in making recommendations to the operations boss whose job it is to implement and enforce the new procedures and processes. In the TQM environment, however, the engineer becomes an equal among peers on the improvement teams. Often this means teaching others how to collect and analyze data. He or she may have to learn team skills. The technical person has to sharpen the ability to listen and to make presentations, thus facilitating communications within and outside of the team. The boss, who once was the fountain of knowledge, finds himself facilitating solutions, not giving solutions. He has become service oriented. He is seen as coach and helper, not as a baby-sitter.

The transition is not made without considerable education and training, especially of the more established individuals. Often, progress that starts out in the classroom must be reinforced at the work place with on-the-job coaching.

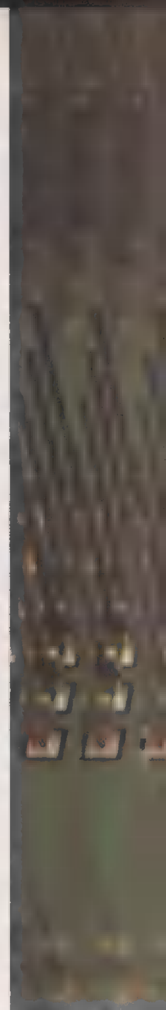
THE CHALLENGE. The TQM culture is dominated by an intense and systematic approach to communications. Every stakeholder—employee, customer, manager, and owner—has to confer with every other stake-holder. In this process, called policy deployment, one tool is the quality policy-planning matrix. This document contains a highly focused set of generic improvements that covers all the areas targeted for upgrading in the plan year. It lists fundamental improvement projects complete with measures of progress, targeted completion dates, and goals. The matrix is formed by top management in the light of inputs from throughout the organization. These inputs ensure that the plans are reasonable and logical. Customer expectations derived from surveys, customer relations, and other sources are also vital inputs.

Once the matrix is complete and approved, it is sent to all the teams. It shows everyone the organization's direction and the improvement projects planned for the upcoming year, and it provides teams with the means to align their efforts at improvement with business directions.

The employees in a total quality environment can best be described as empowered. The challenge is how to empower another individual or group. Empowerment is very personal. One person will take on responsibility under the worst circumstances, while another will fail to act under extremely supportive conditions.

Management's role is to provide an encouraging atmosphere. This means making it all right to fail. Increased participation and responsibility can be encouraged through education and training. Often the development of a new skill or insight will persuade someone to become active in a team.

Teamwork is the outstanding characteristic of the quality improvement efforts. The quality improvement team (QIT) may be a "functional" team focusing on the processes indigenous to one segment (functional area) of the business. Alternatively, it may be cross functional and consist of members from several functional areas. For example, employees from the personnel and the engineering departments might team up to smoothe the movement of personnel between departments. More usually, this type of team is appointed by management to solve a problem too complex for a group from a single area.



Teamwork calls for a significant increase in employee empowerment. Can the middle manager survive and thrive in this world? The answer is a qualified yes, but the job is different from the autocratic role of the past. The modern middle manager is a team player, very visible to and approachable by the people that he or she leads.

STAGES OF GROWTH. Because it is a fundamental shift of business philosophy, a company's transformation to TQM must begin at the top. Often, a chief executive officer gets the idea from a fellow executive, rather than from a middle manager. But once convinced, the chief must take charge of convincing other top managers of the benefits of the new approach. Relegating this job to another would give the appearance of only another flavor-of-the-month management fad.

As the transformation proceeds, the leadership reforms itself into a team and begins to plan and promote the changes. A Quality Champion—one who understands in depth the nature of process variation and can motivate people to change—is the best person to convince managers and employees of the merits of the required changes.

Before employee teams are formed, managers must gain skills in process improvement and team building and employees must be educated in the new methods. Then the teams can begin to improve their processes.

Initially, the leadership needs to focus the teams' activities on areas where process improvements will be most likely to visibly impact the business. This gives them the pleasure of seeing the fruits of their efforts before they are asked to work on harder projects. Then, the organization is ready to take on grander improvements directed by management. Employee success reinforces their focus on customer satisfaction through continued improvement of products, services, and processes.

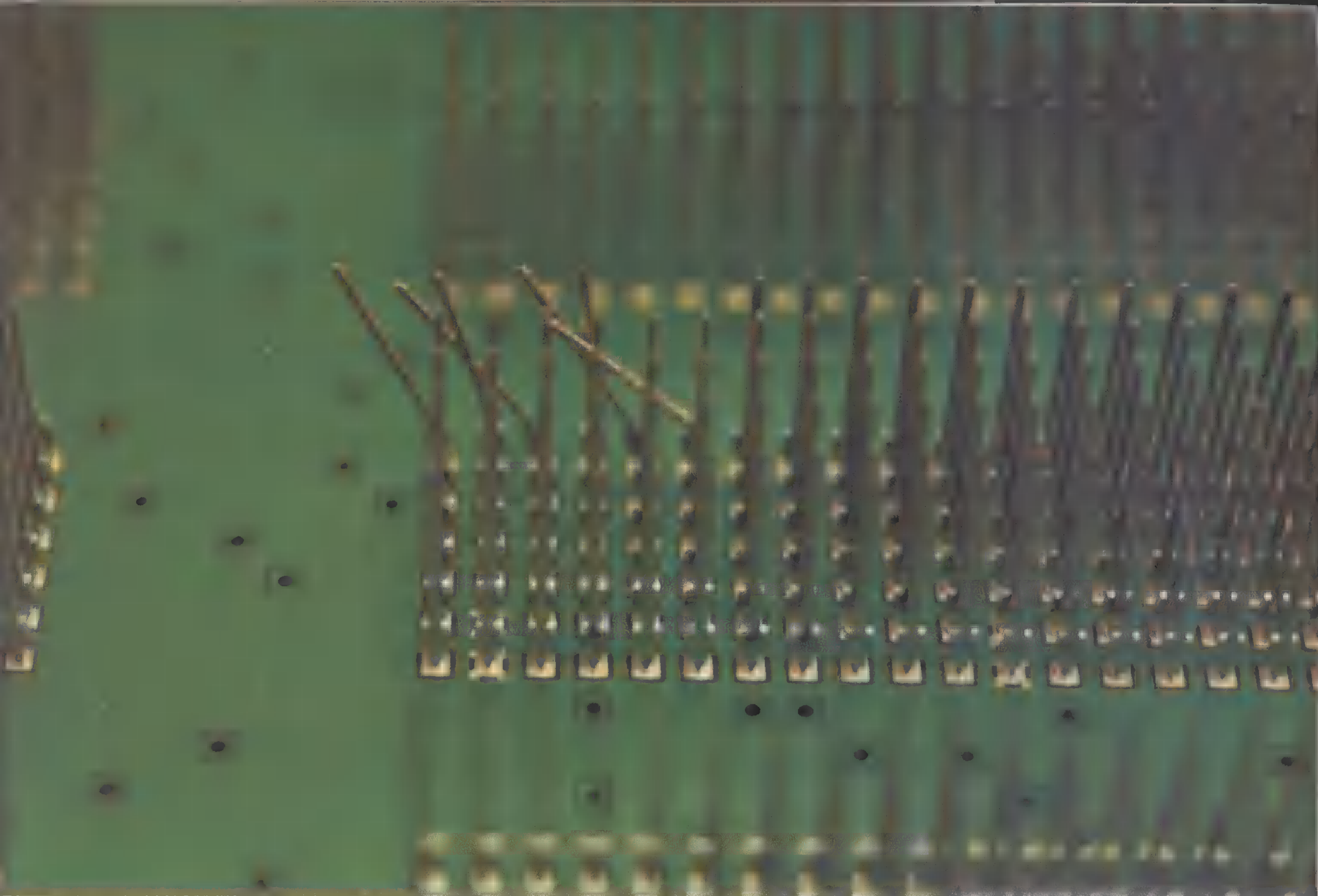
As a company's TQM method matures, performance management systems are established to align the individual and team efforts with business goals.

These transformations do not happen

Part of a quality planning matrix

Direction	Detailed objective	Individual project	Indicator	Goals: 1992	Goals: Long term
2.0 Enhancing quality	2.1 Improving key processes	2.1.1 Manufacturing processes	% processes in beta sites† at 6 sigma	Improve by 1 sigma from end of 1991	100% by xxxx
		2.1.2 Office support	% customer-identified impactors at 6 sigma	Reduce by 1 sigma from end of 1991	90% by xxxx

† Beta sites refers to those processes that were picked to test the 6-sigma process.



A backplane essentially interconnects circuit packs, the functional subsystems of the larger transmission systems. Pins on one side of the multilayer wiring board connect it to the circuit packs. On the other side they provide points to which wires and cables from the outside world are attached, as well as interpack connections. The pins range between 2.5 to 3.8 cm long and have 0.004-cm² cross sections. Retainers secure cable connectors to the backplane. During fabrication, holes are made in the backplane on 0.25- or 0.32-cm centers, and pins inserted through them. Before the TQM team's work at AT&T's Massachusetts factory, bent pins accounted for 20 percent of the defects identified in the process sequence following panel assembly. The team identified four root causes and proposed countermeasures.

overnight—or even in a fortnight. For AT&T's Transmission Systems Business Unit (TSBU), the cultural transformation has taken years and is ongoing. Who knows when it began? In 1989 the executives declared that they were committed to the Malcolm Baldrige criteria as a framework for continuous improvement. Since then the business unit personnel have written no fewer than nine Baldrige applications. Most of these have been internal, in pursuit of AT&T's Chairman's Award.

Even before the official announcement, many management personnel attended Deming's four-day seminar, some as early as 1981. Quality training for everyone is still a high-priority activity. TQM is literally a "race without a finish line."

TWO CASE STUDIES. An improvement effort at AT&T's Transmission Systems factory in North Andover, MA, illustrates how TQM comes together as a system. The team that carried out the study consisted of members from engineering, production associates, supervisors, and a facilitator. This was a "functional team."

Bent backplane pins [see photo] seem always to have plagued engineers. In the summer of 1991 an effort was begun to study and rectify this situation. It lasted 17 months, ending in November 1992.

A backplane is a large, multilayer printed-wiring board that serves to interconnect circuit packs (or circuit cards) that are the functional subsystems of the larger transmission system. During its fabrication, pins are inserted through holes that are located on 0.25-cm or 0.32-cm centers. If the pins are not inserted straight and do not remain straight throughout the manufacturing process, they may cause failures during systems tests and difficulties in inserting circuit packs into the system. Even though the ultimate user of the system is shielded from this problem by final inspections and system checkouts, it is a source of delays and extra cost.

At the outset, bent pins constituted 20 percent of the defects found by inspectors and production associates in the process sequence following panel assembly. The team therefore decided to target this problem. A row of the Quality Planning Matrix [see table, p. 48] relates the team's activity back to one of the fundamental objectives of the corporation: Enhancing Quality. Within this row, key processes (in this case a manufacturing process) are identified and goals for improvement are set.

The team focused on two major offenders, products A and B. This is called stratifying the data; the intent is to optimize the return on effort. For the purposes of this discussion, the bent pin defect rate per backplane is indexed to one [see figure, p. 50]. These products accounted for 53 percent of the total bent pin defects in all products assembled by this shop. The team's goal was to halve the occurrence of this type of defect on these two backplanes.

After brainstorming many causes of bent pins, they identified a few of the worst. The team collected more data to verify their suspicions, consulting both process data and the opinions of users of the assembled backplanes. The analysis narrowed the areas of concern to the first assembly operations and the assembly of retainers.

Armed with this data, the team was ready to pinpoint root causes and develop countermeasures. Four root causes were identified. First, pins were becoming bent during assembly because there was no fixture to hold the backplane. Prior to their being

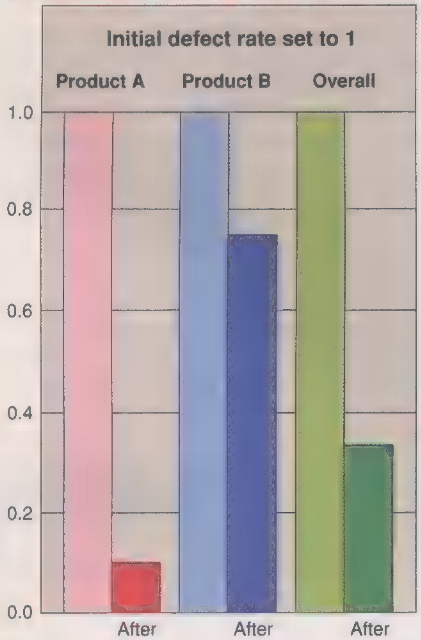
mounted to the shelf frame, the pins are vulnerable to damage. The team also noted that once the backplane assembly was complete and ready to be mounted onto the shelf frame, it was placed on a storage and transportation truck. Pins sometimes became bent because they hit the truck. The team's countermeasure for both of these root causes was to design a holding fixture that could be used on all backplanes during assembly operations as well as during storage and transportation.

A third root cause of bent pins was that they occasionally got bumped as the backplane was placed on the shelf frame. The team thought of two ways to fix this. One way was to design a mounting fixture to guide the backplane into place. Another approach was for two people to place the backplane onto the frame. The latter proved to be the more practical, so the fixture idea was abandoned. Another root cause was traced to a frame alignment arrangement that allowed the frame and the backplane to become misaligned during assembly. Pins suffered damage when temporary alignment ties were removed at the final assembly operation. The addition of a stiffener plate to the frame assembly prior to mounting the backplane eliminated this problem.

The actions required to implement the countermeasures were shared equally by engineers, supervisors, and production personnel.

The resulting 90 percent improvement in product A and 25 percent improvement in product B impacted the performance of all products in two ways: the average number of defects was shifted downward and the

Defect rate due to bent pins



Defect rates due to bent pins were reduced by two-thirds in two products after a quality improvement team identified the root causes and implemented countermeasures.

improvement spilled over to other backplanes. The upshot was a threefold reduction in bent pin defects overall [see figure, below].

The team chose to maintain its gains through some standardizing process steps. In other words, they trained personnel and instituted the use of visual aids and supplemental documentation. After considering the largest contributing defect and inputs from their internal customers, the team decided that even though some bent pin defects remained in their inspection results, their next study would best be focused elsewhere.

To summarize, the team went through a typical PDCA cycle. First they gathered preliminary data and made an analysis of the root causes. Then they implemented countermeasures. Next, they monitored the results to make sure that they improved performance. Lastly, they standardized their process steps and decided whether or not they wanted to continue their efforts on this or some other problem.

DUTCH STUDY. TQM is not just American. It was first practiced in Japan, where it is called Total Quality Control. Continuous improvement aimed at customer satisfaction is now a global phenomenon. This next case comes from Europe.

The study involves the improvement of the functional circuit-pack test yields at AT&T Network Systems International's factory in Huizen, the Netherlands. This team nearly halved the defect rate.

Forty-eight percent of the faults were attributable to soldering problems during the baseline period of April through September 1991. The team set a target to reduce such faults from 48 percent to 10 percent.

The team members chose to investigate causes of defects related to each component on the circuit pack. They began their analysis with a brainstorming session that identified several possibilities, and then focused their efforts on five types. Their investigations led them to the root causes.

One root cause was a component placed in the feed tube incorrectly by the supplier. The team decided that the countermeasure was to prescribe the correct placement of the component to the supplier. In practice, they had the purchasing department contact the supplier and prescribe the packaging in the ordering specification. This example shows how a problem is related to its root cause(s) and then to a practical method of solution.

The team eliminated faults caused by two components. Two more were reduced by factors of 10 and 9, respectively. The defects attributed to soldering were reduced from 48 percent to 33 percent. As stated at the outset, the overall defect level was reduced by nearly 50 percent. The team has concluded its work on this problem for now.

MORE THAN A QUICK FIX. There are those who see TQM as just another management gimmick that will soon fade into the past. But others say, "Let us not be too quick to judge this approach." One of the supporters is Richard S. Wellins, senior vice president of Development Dimensions International Inc. in Pittsburgh. He has said that TQM is still an emerging business strategy and that it does improve organizational performance. But he has also said that there exists a significant gap between successful TQM implementation plans and execution.

There are three emerging areas that will improve both TQM plans and execution. The first is innovation, not limited to products, but emphasizing process innovations and breakthroughs. Second, companies have to understand the entire market, not just their current customers. Through surveys, focus groups, and trade shows, they must garner ideas about what customers and potential customers are thinking and turn them into concrete product service offerings and opportunities for user feedback. Such prototypes become the forerunners of next-generation offerings. One technique for doing this is quality function deployment, a method for determining which features add to customer satisfaction and prioritizing them, then ensuring that they are worked into the design of the product or service.

The third focus is the development or adoption of a disciplined and uniform problem-solving process across the corporation. Such a process allows the team to handle the problem without reinventing the process every time; it also helps a person from outside the team to get quickly up to speed on the status of the solution.

Total Quality Management provides a context in which employees can improve themselves and their companies. At AT&T the pursuit of continuous improvement aimed at customer satisfaction is corporate strategy, and already two business units have won the Malcolm Baldrige Award. Many other electrotechnology firms have joined in this unending race toward excellence, namely, Texas Instruments, Solectron, IBM, and Motorola, all of which have already won.

Employees and managers of companies that apply TQM know that it is more than a collection of procedures and theories—rather, it is a daily struggle to develop and apply better and better methods.

Implementing this approach requires a commitment from the whole organization to focus on the market place, because information garnered there drives improvements in products, services, and production. Clearly this commitment has to emanate from the top executives.

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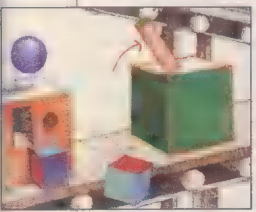
Bringing costs down

As competition in the technological marketplace heats up, turnaround times are shrinking and products and manufacturing processes are becoming more elaborate. Corporations can no longer afford a haphazard approach to design and manufacture. So they are turning to sophisticated, largely computer-based tools to help them track their design and manufacturing processes and their inventory.



One set of products ensures manufacturable and testable designs. Another optimizes the manufacturing process by determining the most efficient way to use tools, personnel, and inventory. Both strive to cut costs and cycle time and enhance quality.

In the first category, engineers at AT&T, and others at Boothroyd Dewhurst and Texas Instruments, have developed software products that focus on the manufacturability of printed-circuit boards. At IBM, engineers have employed computerized models to streamline their production processes.

In Europe, a painstaking analysis and overhaul of marketing and ordering procedures slashed the time it took to specify and order a piece of switchgear from ABB Asea Brown Boveri Ltd.'s switchgear manufacturing operation.

Design for manufacture

Thomas P. Pennino and Jamey Potechin
AT&T Bell Laboratories

Electronic design is a complex undertaking. It is not enough to design for functionality; design must also create a competitive advantage by shortening the interval to manufacturing while yielding products that cost less to produce and are of higher quality. It is no wonder that the discipline of design for manufacture (DFM) has received so much attention. AT&T Co. has certainly found it an admirable approach to designing printed-circuit boards.

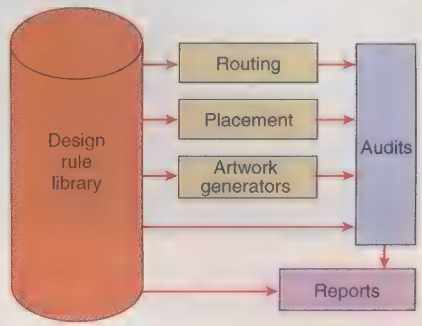
Caught between electrical design and manufacturing, designers of such boards have a truly tough job. They are under intense pressure to finish their work quickly, since every day they spend on it delays getting the product to market. They must stay abreast of the evolution of device packaging and manufacturing processes. They dare not let mistakes slip through to manufacturing, because extra "turns" back to design delay project schedules. Clearly, they need sophisticated tools to help them apply DFM.

Starting in 1985, AT&T began to push the use of DFM in its systems design and manufacturing divisions. Designers use an array of software tools developed within the company over the past 20 years by both design and manufacturing. The tools include software audits and manufacturing generators that fall into three main classes: design for fabrication (DFF), design for assembly (DFA), and design for test (DFT). The DFF tools deal, for instance, with mask design and test coupon generation; the DFA tools with board assembly, such as parts clearance for assembly and optical inspection; the DFT tools with board testing, including bare-board testing (done after boards have been fabricated) and in-circuit testing (done after they have been assembled).

DESIGN RULES. The guiding light of these DFM tools is a system of design rules, encompassing more than 30 categories, that are used by the generators and audits to ensure that designs meet their manufacturing-related needs [see figure, at top]. The rules capture the requirements of factory processes so that the needs of manufacturing are considered automatically in the design process. Further, they are flexible, and can be easily adapted to the requirements of different products, factories, and manufacturing processes.

To understand how design rules are used, consider what is involved in inserting through-hole components into a printed-circuit board. An automatic component-insertion machine uses an insertion head that overhangs the part by some distance. To avoid collisions, parts next to the one being inserted must be no closer to it than the overhang distance plus some tolerance. A clearance design rule captures this requirement by specifying the area around the part that must be free of other parts.

The design rule allows the area to be a function of the part type, since different insertion heads may be used for different parts. The rule could even be made specific to an individual part, a course that might be taken if the part were destined for manual assembly, where collision is not a concern and the clearance area need not include an overhang.



Design rules, generators, and audits ensure manufacturable designs by capturing process requirements and analyzing designs for violations.

This system of generators, audits, and design rules is a powerful way to ensure manufacturable designs. Board-manufacturing data is captured in design rules used

Defining terms

Audit: a software tool that examines design features to ensure that they adhere to the design rules.
Bare-board test: the testing of circuit boards after fabrication, usually on a bed-of-nails tester that contacts points on the board with spring-loaded probes and checks for short and open circuits.
Generator: a software tool that automatically generates design features. For example, a solder mask generator creates a mask pattern of openings around each terminal that must be accessible.
Gerber data: an industry-standard data format for artwork for circuit board manufacturing, developed by the Gerber Corp. for use with its plotters.
In-circuit test: the process of testing boards after components have been assembled. It is generally done on a bed-of-nails tester and checks for the proper operation of circuits on the board.
Mask level: a collection of related design elements for an entire board, usually corresponding to a single manufacturing process step.
Nomenclature: a pattern applied to a circuit board to provide alphanumeric information.
Solder mask: a dielectric coating applied to the outer surfaces of a circuit board to protect board circuitry and prevent electrical shorts between adjacent circuitry.
Solder paste: a paste made with solder that is applied just before component placement to pads that will have components soldered to them.
Test coupon: a preset pattern of copper pads and/or holes used for testing during manufacture.
Venting pattern: a pattern of openings added to large regions of copper to allow moisture to be released from the board substrate material.

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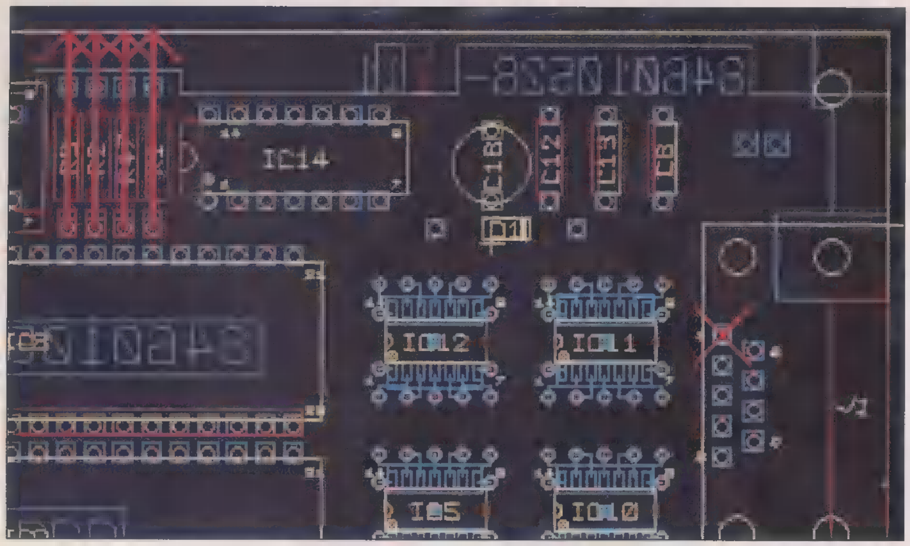


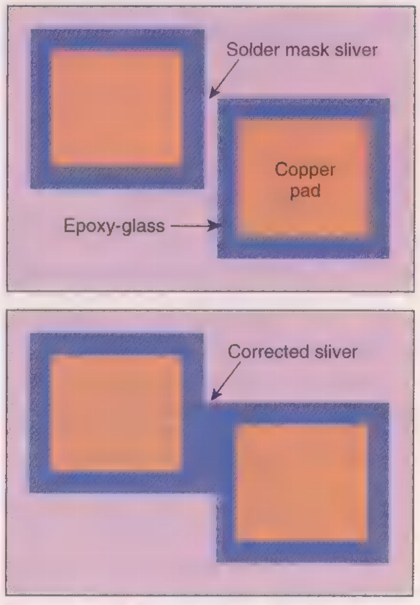
Design rule violations can be listed as text or displayed graphically, as above. Arrows, Xs, and other symbols show designers where violations have occurred and how to fix them.

A sliver may be created when solder mask openings around neighboring copper pads are too close together, leaving a thin strip of solder mask between them [see figure, below]. But the solder mask generator would eliminate this sliver by adjusting the solder mask pattern. Thanks to the flexibility of the design rule system, the designer can set the threshold for how thin a strip of solder mask must be before it counts as a sliver. This threshold can vary depending on the type of solder mask used and its adhesion properties.

OTHER APPROACHES. An alternative to DFM is to audit the Gerber data used to create artwork for a printed-circuit board. This approach has serious drawbacks. First, Gerber data audits can be used only after the design is complete, which is too late in the design process. Second, artwork data audits cannot check areas of the design whose purpose must be understood, and so cannot detect when the design is wrong. AT&T's DFM tools deal with every stage of the design process, including handling the changes that are part of design revisions. Some changes are made interactively by means of manual editors, while others are made by rerunning the generators. In either case, the design rules and audits are there to maintain manufacturability.

Reviewing the complete design before release to manufacture takes about 30–45 minutes of the designer's time for a typical six-layer board design. Most of this time is devoted to exception analysis and deciding whether to correct problems that have been flagged.

Several years ago, however, several highly skilled AT&T technicians needed about a day to do a DFM review manually; a further one to three weeks was required to make decisions on the types of errors found



Solder mask audits check for slivers and correct designs that contain them. Design rules are adjustable to set the width below which a strip counts as a sliver.

by all the DFM tools. The design rules and DFM tools guarantee that a given design can be manufactured in the targeted factory.

The design process begins when the engineer accesses the design rule catalog for the product line, technology, and factories to be targeted. He or she may change some rules to take into account specific attributes of the design or a new factory process. Once the rules have been set up, the physical design can begin.

First, an automatic placement tool places parts on the board. The designer may also use a manual editor to place critical parts. Parts audits are run to verify that parts are far enough apart and that they are placed properly for a solder wave or solder reflow process. The engineer may then want to confer with the assembly factory. Using a design conferencing feature built into AT&T's system, the designer and factory engineer can view the same layout on their respective screens and interactively solve placement problems.

Next, an automatic layout tool routes the interconnections between part terminals, employing the same design rules used by the other generators and the audits. Interactive changes may be made throughout the layout process to complete connections that were not routed automatically or to change existing connections. The designer runs automatic DFM generators to make venting or mesh patterns in power and ground planes and to build coupons for testing multilayer registration.

Bare-board testing and in-circuit test audits are run to ensure that the board will be testable after fabrication and assembly. A host of other audits check clearances (part-to-part, metal-to-metal, hole-to-metal, and hole-to-hole), hole size, and so forth. Still other audits cover such electrical and correctness concerns as connectivity and cross talk. Nonmetal generators create mask levels for solder mask, solder paste, and nomenclature.

Once the design is complete, the designer runs all the audits one last time—including audits to check the generated data for solder mask, solder paste, and nomenclature, since these patterns can be edited manually—just in case something has been overlooked. As a final step, output functions are used to produce the required factory outputs for all the mask levels.

AUDIT VIOLATIONS. The audits that the design engineer runs throughout the design cycle analyze the design data for violations of the design rules, and flag any that occur. The violations, listed textually in reports, can be displayed on screen with graphics that are designed to be intelligent—in other words, to help the designer understand and fix the violations. [See figure, above.]

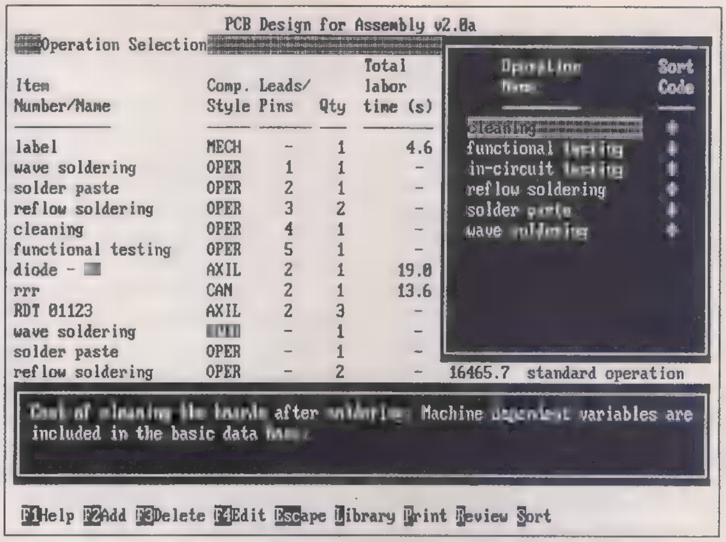
Arrows in the figure warn that the holes defined for the resistors beneath them are too close together given the intended span of the resistors; the tips of the arrows indicate where the holes should be located. Rectangles mark adjacent parts that are too close together, and their width shows how far the parts must be moved for clearance to be adequate. An "X" [on the right side of the figure] warns that a part is located in a region that should be free of parts. Graphical query functions allow the designer to point to each graphic and ask the system for specifics regarding the violation. The designer judges whether it must be corrected, makes the correction if necessary, and then steps through the next violation.

DFM TOOL EVOLUTION. All of these audits arose out of a manufacturing need, and their breadth and sophistication embody years of manufacturing experience. Consider the solder mask audit checks for the thin strips of solder mask called slivers. Experience at AT&T's printed-circuit board factory in Richmond, VA, showed that slivers tend to flake off and clog processing equipment or stick to some other part of the board.

and the joint engineering and manufacturing recommendations for correcting them. According to our industry estimates, it takes two to three weeks to uncover errors and correct them in a typical six-layer board design and manufacturing process without design-for-manufacture tools. Some problems are found in design but most are discovered during manufacturing. Scrapping even a small lot (10 to 20 units) of six-layer circuit boards because of design and manufacturing errors costs about $3500 in material and labor outlays. Much more serious is the loss in time to market. With the help of the DFM tools, AT&T designers can complete their designs in hours instead of weeks, with every confidence that they will flow smoothly into manufacturing.

AT&T's DFM tools are used widely within the company and have helped AT&T's Transmission Systems Business Unit win the Malcolm Baldrige Award for quality. A subset of the DFM tools, specifically the design-for-assembly audits, is currently available to the external market through a partnership with Cadence Design Systems Inc. on its Allegro system. The entire suite of DFM tools will be offered for sale to the external market. Their availability will be announced in October.

ABOUT THE AUTHORS. Thomas P. Pennino is head of the computer-aided design department at AT&T Bell Laboratories, Holmdel, NJ. He oversees software development for AT&T's interconnection design system for circuit boards and backplanes. Jamey Potechin is manager of the design for quality and manufacturing group of the computer-aided design department at AT&T Bell Laboratories, Holmdel, NJ. He oversees development of manufacturing-related software tools for AT&T's interconnection design system.



Called from Boothroyd Dewhurst's PCB/DFA operations library, this screen highlights a cleaning operation. The labor rate for cleaning a given board has been entered, along with the product lifetime volume and number of cleaning setups, into the library, from which cleaning costs are calculated.

CASE STUDY
TI & Boothroyd Dewhurst

Design for assembly

Geoffrey Boothroyd and Winston Knight
Boothroyd Dewhurst Inc.

Concurrent engineering and design-for-manufacturing efforts in the electronics and other industries are steadily superseding the costly practice of manufacturing a system to a quite unfamiliar design. In the new climate, designers and manufacturing engineers work together, and the teams are asking for software that meshes design with manufacturability.

Design-for-manufacturing software programs give the designers of printed-circuit boards (PCBs), well ahead of time, a better idea of how densely populated with parts a finished board will be and what manufacturing problems it will present. Concurrent engineering teams are also asking for automated tools that enable them to predict not only board density, height, and other physical properties but also what the finished board will cost to manufacture.

For more than a decade, Texas Instruments Inc., Dallas, has worked on a parts-based system of analysis that predicts the cost of manufacturing a circuit board. Meanwhile, Boothroyd Dewhurst Inc., Wakefield, RI, was gaining experience from its commercial Design for Manufacturing and Assembly (DFMA) software, and six years ago joined forces with TI to apply that experience to circuit boards. The DFMA software was developed in 1980 for analyzing the manufacturability of mechanical designs. During the conceptual stage of a product's development, the software makes a comprehensive analysis of a design, its materials requirements, manufacturability, and estimated cost, allowing an engineer to build an information base for evaluating the manufacturability of a design step by step. Using results obtained by the software, Ford Motor Co. showed that 80 percent of all product costs are fixed at the design stage.

MANUFACTURABILITY INDICES. Together, TI and Boothroyd Dewhurst have evolved a software program that not only predicts a board's cost but also provides indices of its manufacturability. Called PCB Design for Assembly (PCB/DFA), the software is intended to reduce design-cycle time and manufacturing cost. Well before placement and routing, the software quickly generates "on paper" alternative board designs that would be economical to manufacture.

Tim Bogard, senior account manager for concurrent engineering products in TI's Information Technology Group in Dallas, has worked in product engineering at the company for 15 years. He and his colleagues recognized flaws in the liaison between product design and assembly, and in about 1980 founded an organization, Producibility Engineering, to deal with the problems.

The group's task was to define the requirements of the automatic assembly and insertion equipment used in assembling circuit boards. Those requirements included cleaning and presoldering components, lead forming, and loading parts into assembly machines in a prescribed order.

Fabricating the boards themselves had become highly automated, Bogard pointed out, but little thought was being given at the design stage to the assembly and test of loaded boards. "We knew we had to do things differently, so we [in Producibility Engineering] started to work with design engineers to act as consultants on manufacturing as they started their work."

But too little time was left over for the analysis of the implications of applying the different kinds of assembly required for the various types of component packages. "That process, which was basically manual, might take two to three weeks, and the design engineers would not wait that long," Bogard said. The designs still were not completely compatible with manufacturing methods.

It became clear that a component database was required that would automatically analyze the design's manufacturability. Bogard's group set up the first such database at TI in 1984, and soon learned that it had to be easy to use if the design engineers were, in fact, to use it routinely. People wanted to hit a button and have design guidelines and a parts list come out.

That same year, Bogard's organization produced just that push-a-button technique. This was a component-based software package that contained design guidelines based on the company's policies and procedures. The software also had an intelligent interface for ease of use. The first iteration was called DB-2 and was like a Lotus 1-2-3 spreadsheet.

A second generation incorporated an ar-

tificial intelligence (AI) engine that had captured the knowledge of experts in assembly and manufacturing. According to Bogard, however, TI has not needed the AI engine/expert system, because board manufacturing rules, contrary to belief at the time, have turned out to be more science than art. PCB/DFA is the third generation of the tool.

TI and Boothroyd Dewhurst started collaborating in 1987 on a version of TI's component-analysis system. They released an early version of PCB/DFA in November 1991, and the first commercially viable version the next July. The package combined major elements from BDI's DFMA and TI's component-analysis system.

WHERE IT STARTS. PCB/DFA comes into play at the time of component selection, well before the placement and routing steps of computer-aided design programs. The starting point is a schematic of the circuit. The software's Lotus 1-2-3-like "spreadsheet" is used to predict a circuit board's cost and assembly time before any detailed design work on the board itself takes place [see figure, p. 53]. The cost totals also include costs of the board and components themselves, as well as testing and rework of a finished board.

With the software, users put together a list of the electronic components that will meet the functional requirements of the board as specified in a schematic diagram. These components may be selected in two ways: either from master or standard parts lists or else as specified by the user. Parts in the master list are identified by part name or number and can also be chosen directly from existing company databases. They are also associated with a database of standard package styles. The user, too, must associate each of his or her parts with a particular package style and size from the same database.

As each item is selected or specified, data and manufacturing knowledge are retrieved for use in later analysis of the proposed circuit board. The preferred methods of insertion, or placement, and soldering are also indicated.

When the parts list has been completed, the PCB/DFA software goes into action. It calculates the density of the parts on the board and the height of the board and its parts. It analyzes the manufacturability of the board with the auto-insertion equipment the company has on its production line, the cost of assembly, and the board's quality, and ease of manufacture. The software also produces a design rating for the board that is an index of its manufacturability. And of course, the software calculates the cost of producing the stuffed board. Subsequently, "what-if" analyses may be performed, say, by substituting components or by moving parts to other places on the board.

PARTS DATABASES. Parts in master or standard parts lists are identified by a name or number that appears in a database along with the generic name (including package type and size) and cost.

Generic descriptive names also appear in a separate database of package styles included in the software. The database is accessed by specifying the style (axial, radial, plastic leaded chip-carrier, and so on) and electrical function. This gives entry into separate sections of the database that list different packages, usually referred to as sizes, within each part category.

Dimensional and manufacturability information is associated with each item in the database. The manufacturability data includes such items as the most used insertion and soldering methods, area and height required on the board, and any special operations required, which, if manual, increase labor costs and manufacturability problem codes.

The last-named codes specify manufacturing and other problems affecting each part style and size. Also called out are the percentage of parts with problem codes associated with them—problems that could result in lowering quality, increasing labor costs because of the likelihood of rework, or making the board more difficult or costly to manufacture.

The problem codes are contained in a user-maintainable list furnished with the software. An example might be that the leads on a certain part tend to bend in handling. Associated with each problem code is a numerical index of its relative importance; this index is used in subsequent analyses and in the rating scheme that grades the board's manufacturability.

A valuable output of this system is an estimate of the assembly cost of the proposed board. The estimate is reached by using databases of cost-related information for the various automatic insertion and placement methods that will be used; other databases specify the duration of manual and semi-automatic insertion and placement operations; and libraries contain equations for estimating the cost and the time needed to perform special operations.

These special operations may be standard steps for specific components or board-related operations, such as solder paste screen-printing, reflow and wave soldering, testing, and board cleaning. An extra facility lets user-defined operations be added to the library.

Cost equations are also a feature of the library for standard secondary operations associated with specific components; involved with these operations are such items as hardware mounts and additional heat-conducting compounds, bonding components, and tie wraps.

USER INPUTS. Users enter the design data, including the board technology (through-hole, surface mount, or mixed), electronic function (analog, digital), dimensions, type of mounting, and maximum design requirements. The last include entries such as component height, board thickness, and keep-out areas.

Design requirements for different technologies and electrical functions are stored

Other DFA software

At least two other design-for-assembly software programs are available. They are MA/PCB from Mentor Graphics Corp., San Jose, CA, and DFA (Design for Assembly) developed by AT&T Co. and sold as part of the Allegro PCB and Allegro Correct-By-Design system design environments from Cadence Design Systems Inc., San Jose, CA.

The PCB Division of Mentor Graphics is a strategic supplier of electronic design automation tools to Texas Instruments Inc., said that company's Tim Bogard. TI and Mentor have worked together to integrate TI's in-house component analysis software into Mentor's Falcon Framework for Concurrent Design. The result is MA/PCB, for Manufacturing Advisor/Printed Circuit Boards, a TI-developed application program sold by Mentor Graphics

"We wanted to get all our tools for engineering automation incorporated into the same environment," Bogard said. That design environment also encompasses a uniform user interface, databases, and peripheral support. The programmable user interface in Falcon is based on the Motif standard of the Open Software Foundation.

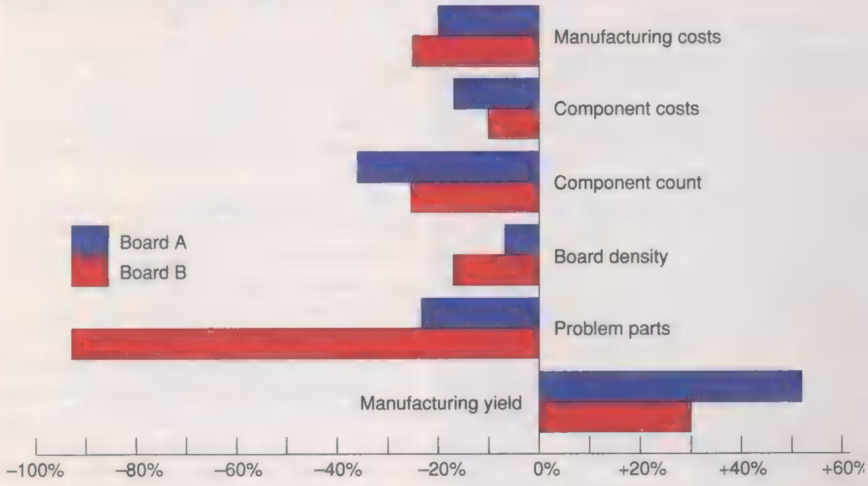
MA/PCB is Unix-based, offering Mentor Graphics customers "a nice solution to PCB design-for-manufacturing problems that's tightly integrated into the Falcon Framework," Bogard said. MA/PCB is similar to Boothroyd Dewhurst's PCB/ Design for Assembly in that it is a predictive (prelayout) analysis tool that generates data on the manufacturability of components being considered. Area consumption, height needs, labor content, special process requirements, standards compliance, and auto-insertability are all included.

MA/PCB runs on Unix workstations and is dedicated to the Falcon Framework. PCB/DFA, on the other hand, is "generally applicable to DOS-based personal computers," Bogard said. Currently, MA/PCB does not include a component cost-analysis feature, but it will be included in the next release. Mentor Graphics offers MA/PCB as third-party software; TI does not sell the program. Both Boothroyd Dewhurst and TI sell PCB/DFA.

The AT&T/Cadence software, developed by AT&T Bell Laboratories, is licensed to Cadence and integrated into Allegro. It is used during board layout, but before routing. Among other features, the product identifies components that do not match automated assembly rules and verifies that clearance between board components is adequate for automated assembly equipment and for inspection and repair. User-definable rules allow factory-specific or unique process requirements to be verified. The AT&T/Cadence software runs on Sun and IBM workstations. [See related article on p.51.]

—Linda Geppert

Improvements due to design for assembly



Using PCB Design for Assembly, Evans and Sutherland Inc. reduced costs and problem parts while increasing yield on two circuit-board subassemblies.

in the system and maintained by the user. For example, the maximum usable area on digital boards is usually greater than on analog boards. These qualifications contribute to the board-design rating evaluated by the system. The rating may assign an alphanumeric score—an 80, for example, on a scale of 100—so that users can weigh the comparative manufacturability of different approaches.

Once the design data is entered, parts are selected automatically by the system from the master parts lists, or by the user through the package-style database. Components are allocated to appropriate sides of the board. The most-used (default) insertion and soldering methods are associated with selected parts. These can be changed if a certain piece of equipment is unavailable, however. For example, the default methods may indicate a radial inserter as the preferred assembly equipment. But if one is not available, the PCB/DFA user can enter a substitute method. Some components may have associated with them a choice of secondary operations and hardware necessary for assembly, from which a user can choose the methods most appropriate to her or his company.

At about this point, the program is asked to carry out the parts analysis, including calculating the density and height of the board, manufacturability rating, and so on. The designer supplies data, such as the number of boards to be produced, average batch sizes, and number of individual boards per panel.

Any additional assembly-related operations (cleaning, testing, conformal coating) are selected from the operations library. However, the appropriate soldering processes are added automatically, depending on the components selected. The program then estimates the total cost of making the board, including rework, together with a breakdown of the costs for different placement methods.

Corporate cultures often present obstacles to the adoption of design-for-manufacturing techniques. A few key ingredients are needed to ensure that the typical user of manufacturability software—the product design engineer—accepts it.

First, the program must have a "champion" at the company; that person should be involved in either design or manufacturing. Secondly, someone who can readily understand its potential effectiveness must sell the program to users who are involved in design.

It is also important to have a design-for-manufacturing success story as soon as possible, to demonstrate the program's value, whether at the user company or at a competing company. Essential, too, is the support of corporate management.

In fact, Dick Olsen, of Evans & Sutherland Inc.'s Simulation Division, Salt Lake City, UT, said that getting top management to buy into the effort is key to the success of any design-for-manufacturing program. Olsen is a transition engineer in advanced manufacturing engineering at the division, which uses PCB/DFA. In that capacity, he acts as liaison between design and manufacturing, making sure that product teams from both groups get together early in the design stages.

Extensive changes in the relationship between design and manufacturing are essential before design-for-manufacturing programs can be effective. Getting people together to discuss the manufacturing implications of design is essential if there is not yet an emphasis at the company on concurrent engineering.

ASSISTING SIMULATION. Olsen's experience at Evans & Sutherland is probably typical of PCB/DFA users. The division needed a program to help with mechanical design work "because we were doing a lot of things wrong as the result of designing many one-of-a-kind systems," said Olsen. The division manufactures image-generation systems for simulators used in applications like flight training and military-combat scenarios.

Olsen was hired to help implement a transition-engineering program—a variation of concurrent engineering—aimed at linking design and manufacturing more closely. Before he joined the division, the practice was for designers to design a product or subsystem, then give it to manufacturing to produce. This was the old "throw-it-over-the-wall-to-manufacturing" technique.

Evans & Sutherland initially obtained and used DFMA mostly on mechanical equipment, such as chassis and backpanels for circuit boards. Olsen said that the use of DFMA resulted in typical savings of 20–30 percent on parts cost, and 30–40 percent in manufacturing time.

The division then sought a software program to help quantify and improve its efficiency in designing and manufacturing completed circuit-board assemblies, because it was difficult to predict board density and cost. Olsen said that PCB/DFA meshed well with transition engineering/concurrent engineering "as an integral tool. It was not the main motivator for us to move to transition engineering, but it helped reinforce our decision."

Evans & Sutherland has a three-tier computer network, anchored by Digital Equipment Corp. VAX clusters and servers that are linked to 386-based PCs. The software is being implemented on the network to make it accessible to mechanical and circuit board design engineers spread over six buildings.

Olsen served initially as the PCB/DFA champion in the division. "Once I'd convinced our people to buy the program, I was the only user at first, and designers approached me to rate their designs. Now that they've seen the benefits, we're looking at the program as a way to quantify and qualify everything we do," Olsen said.

The benefits include substantial savings in manufacturing and component costs, improvements in manufacturing yields, and, importantly, alerting designers to problem parts [see figure, above].

"The problem-parts report is one of the most important contributions we've seen from the program," Olsen said. "We've been able to avoid "using parts that had lead times of 100 days or more."

Finally, the program pinpoints overall board costs. "When a manager asks an engineer what the board will cost, the engineer has an immediate answer," Olsen said.

ABOUT THE AUTHORS. Geoffrey Boothroyd is president and cofounder of Boothroyd Dewhurst Inc., Wakefield, RI, and Winston Knight is vice president. Both are professors in the department of industrial and manufacturing engineering at the University of Rhode Island, Kingston.

STEP—the Standard for The Exchange of Product model data

The exchange of product model data plays a key role in the integration of engineering and manufacturing systems. Former standards for data exchange, like the U.S. IGES (Initial Graphics Exchange Specification), the French SET (Standard d´Echange et de Transfert) or the German standards for the exchange of standard parts, homed in on such specific product aspects as geometry, technical drawings, functional charts, or parametric design. But with engineering and manufacturing systems growing in complexity, it has become essential that all critical and relevant product specifications be available on computer-based tools during the entire engineering and manufacturing process. This is not to denigrate the earlier standards, important as they were to the introduction and connection of computer systems.

The new STEP, however, will significantly improve upon them in several ways, including: representing *all* critical product specifications, like shape, material, tolerances, behavior, functional description, and product structure; considering the *whole* product life cycle, defined as all phases of product development, manufacturing, use, and disposal; and specifying process sequences for specific branches of manufacturing, like architectural engineering construction, ship building, car manufacturing, or plant engineering.

STEP will also satisfy requirements for a standard that can be enhanced, that is, one easily and quickly upgradable to accommodate future developments. For manufacturing, such expandability depends on the availability of: a useful product architecture representing different aspects of the product; precise constructs to specify what will be required of workers and manufacturing systems during engineering and manufacturing; a formal language for specifying and implementing the standard; an architecture of implementation and standards for software modules; and test methods and cases to provide the user with well-tested software.

STEP was created in committee TC184/SC4 of the International Organization of Standardization (ISO), of Geneva, Switzerland, and will be published as ISO 10303. It will be released in several parts, the first of which was to be registered as an international standard last summer in Geneva, after eight years of development. Further parts will be published soon.

In all likelihood, a number of commercial systems will provide STEP-based solutions soon, as key vendors embrace development and implementation of STEP. Special interest groups hope to influence the acceptance of the new standard, namely the U.S. PDES Inc., the British Cadettc, the German ProSTEP organization, the French Goset, and the Japanese STEP Center—*A.J.S., B.S., and K.Z.*

Concurrent engineering

Adolf J. Schwab, Bruno Schilli, and Klaus Zinser
ABB Asea Brown Boveri Ltd.

Few would dispute that manufacturing has entered a period of tumultuous change. But despite all the talk of "time-based management," "engineering-change handling," and other concepts of the moment, the basic principles governing manufacturing success remain unchanged. A product still must make much more money in sales over its market lifetime than was spent on developing and producing it.

Since time is money, as the old saw goes, success often depends on a market lifetime that is long in comparison with the time it takes to develop the product and set up manufacturing. Here, then, is the crux of the matter. Product lifetimes (and hence pay-off times) are shorter than ever, thanks to rapid rates of innovation forced by increasingly aggressive and global competition. At the same time, unfortunately, development and manufacturing cycles are being stretched, and by much the same force: aggressive, global competition has raised customer expectations of product performance, quality, safety, and environmental compliance. In many industries, the ratio of product lifetime to pay-off time is getting dangerously close to unity, and threatening to go even lower.

Since the lifetime of a product is determined for the most part by market forces largely beyond the control of manufacturers, their only hope lies with the other half of the ratio. Thus manufacturers everywhere are striving to slash the time and costs of development, engineering, and manufacturing.

In companies where manufacturing is already highly automated, further improvement is now focusing on the engineering and planning phases of the product life cycle, as well as on the preparation of the production sites. "Time-based management" and "engineering-change handling" are just jargon for the functions of any successful manufacturing operation: redesigning process sequences and products, managing information, concurrent engineering, and that most elusive of activities, nurturing cultural change.

In a sprawling, international enterprise, it can be a monumental challenge just to instil a uniform understanding of terminology, processes, methods, and the flow of information—without which no dynamic manufacturing operation can function. The conceptual modeling of whole enterprises in enough detail to distinguish among subtle differences in products, processes, and organizations is essential if information systems are to be integrated throughout such enterprises.

This kind of conceptual modeling, moreover, facilitates the future development, redesign, and refinement of products and processes. Tools supporting this sort of enterprise modeling are fairly mature and widely used, and are available with graphical or more traditional interfaces. Individually, they cannot, however, model the many aspects of a complex enterprise. So a tool is often chosen in terms of the specific improvements its users hope to effect.

The further spread of these tools now depends in part on the adoption of effective standards for data exchange, sophisticated user interfaces, and customization. Just as manufacturing is rife with standards for communication, manufacturing and assembly automation, and machine control, so, too, can engineering and planning processes benefit from more consistency. After all, these processes require procedures and mechanisms not unlike those of manufacturing processes.

For example, parts or components shown in a technical drawing are described by a wealth of data, including the name, number, classification, and version. Similarly, each step in complex engineering and planning processes must be accompanied by the name of the larger task it pertains to, a sequence number, and so on.

Such standardization efforts are already well under way. The Standard for the Exchange of Product Model Data (STEP), formulated under the aegis of the International Organization for Standardization in Geneva, Switzerland, as ISO standard 10303, was recently partially released. It covers basic constructs and application aspects of enterprise modeling, as well as methods of specification and of implementation of complete engineering and manufacturing sequences [see "STEP—the Standard for The Exchange of Product model data," upper left].

This STEP standard is bound to have considerable impact on systems for product development and manufacturing planning (such as computer-aided design and engineering, or CAD/CAM, systems), compelling vendors to offer modeling tools for product specifications like tolerances, surface characteristics, or material behavior. From the start, the standardization process has been inclusive: future users, engineering and computer-science experts, and vendors of commercial systems are all involved in the endeavor.

Wide acceptance of this standard is nevertheless not assured. It will depend on quick implementation of translation software and STEP-based engineering databases for specific application domains like construction, mechanical and electronics design, automobile manufacturing, and ship building. Furthermore, acceptance will be conditional on the quality of the commercially available software—though it is expected to be excellent because of the use of the formal language Express for the specification of the standard in combination with software generation tools, which will

allow the partly automatic generation of translation software and engineering data bases.

Nor will the trend to object-oriented systems be ignored in all this. STEP part 11 concerns the use of the object-oriented language Express in connection with existing object-oriented database management systems.

Our employer, ABB Asea Brown Boveri Ltd., is actively applying the principles of enterprise modeling, not only to specific engineering processes, but to whole business areas on an international level as well. This highly coordinated, companywide effort involves ABB's corporate research centers, traditional ABB information-processing organizations, and the engineering experts in ABB's business operations.

In the following two examples, enterprise modeling was combined with a redesign of process or product to shrink the time to market.

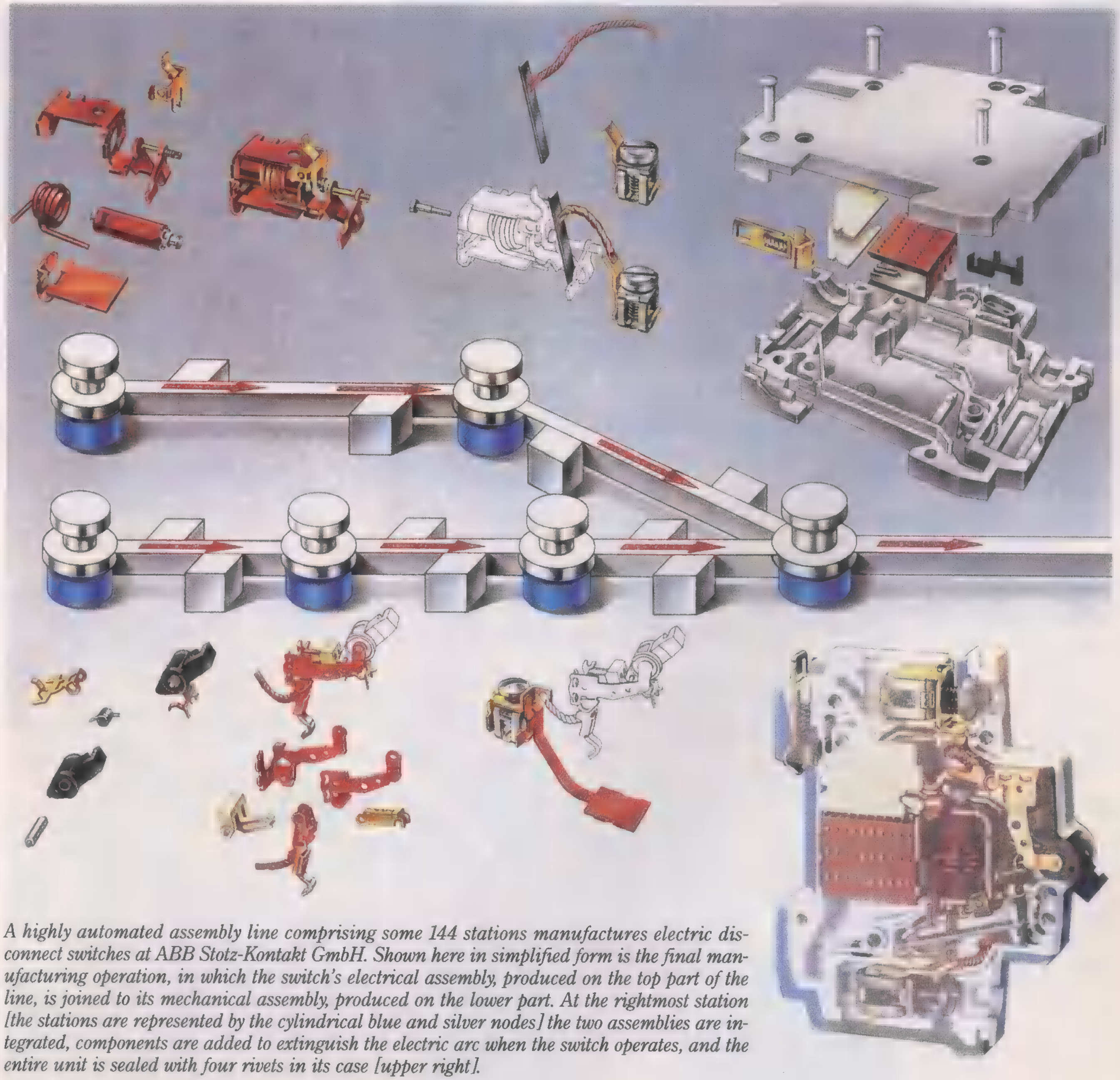
CASE STUDY NO. 1

Miniature circuit breakers

Automated manufacturing was introduced some seven years ago at ABB Stotz-Kontakt GmbH, a Heidelburg manufacturer of electric overload switches, also known as disconnect switches or switchable fuses. Today, four assembly lines produce millions of different switches per year. Each assembly line is optimized for particular groups of products, which may each have up to 100 varieties of product. An individual overload switch is assembled from about 50 parts, of which up to 30 are elemental parts and the remaining 20 are pre-assembled in as many as 10 subassembly groups.

All the production lines were set up for just-in-time manufacturing, in which the materials and parts are brought to assembly at the very moment and point of production. The lines' just-in-time characteristics were determined by storage requirements, material flow, and cost of each of the parts, all juggled so as to produce a continuous output of switchgear covers (accorded this special treatment because they require the largest storage volume). Other components are fed from storage containers along the line. Large, four-hour buffers decouple manufacturing phases from individual stations on the assembly line and thus ensure a high total availability of the whole manufacturing process and hence high production rates of the finished item.

From the start, the switches were de-



A highly automated assembly line comprising some 144 stations manufactures electric disconnect switches at ABB Stotz-Kontakt GmbH. Shown here in simplified form is the final manufacturing operation, in which the switch's electrical assembly, produced on the top part of the line, is joined to its mechanical assembly, produced on the lower part. At the rightmost station [the stations are represented by the cylindrical blue and silver nodes] the two assemblies are integrated, components are added to extinguish the electric arc when the switch operates, and the entire unit is sealed with four rivets in its case [upper right].

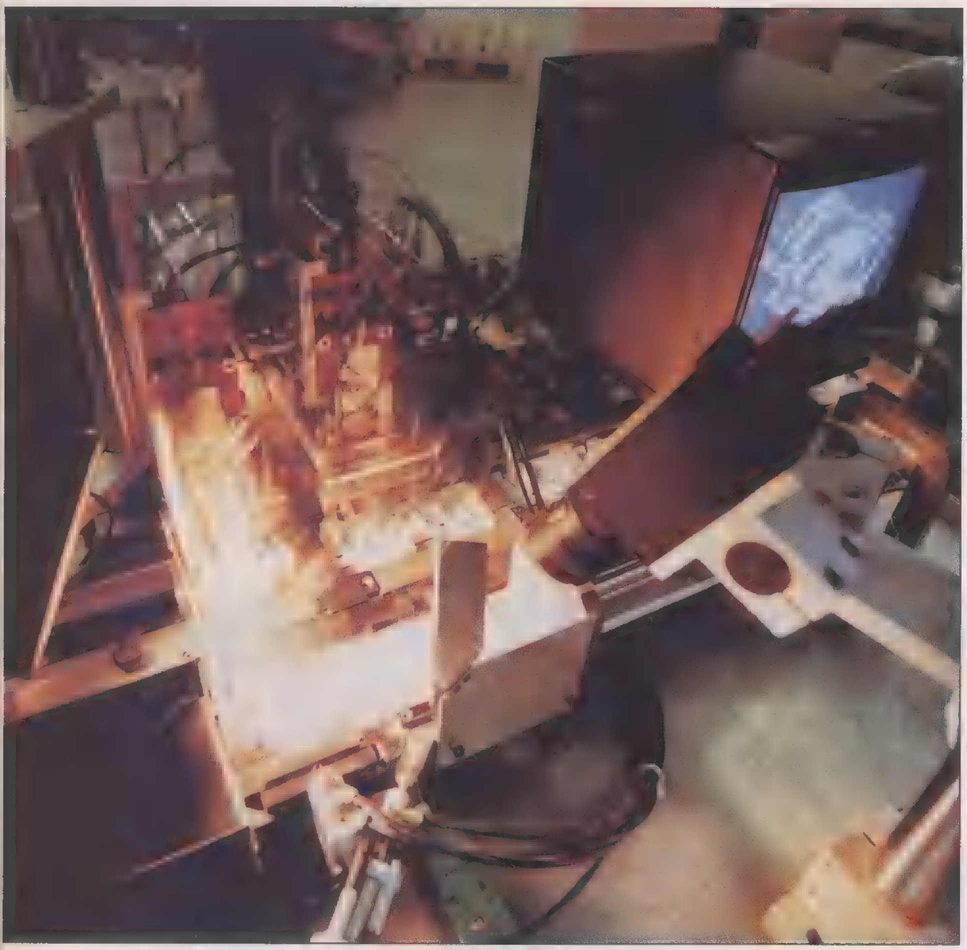
signed with automated manufacture in mind. Most of those design features facilitate the feeding of the component parts to the assembly line.

Also important is the fact that the part tolerances permissible during assembly are tighter than for the normal operation of the device: thus a newly assembled switch at least operates. Overall, there are about 30 test stations, so that less than 1 percent of the switches come off the line with defective parts.

This highly automated manufacturing scenario works well for the unexceptional, "run-of-the-mill" switches that constitute 80–85 percent of the plant's output. At maximum capacity, one of these switches can be produced every 2 seconds.

However, custom-designed switches make up the other 15–20 percent of product volume, and here such a high degree of automation is not economic. The approach instead is to shorten the order-to-delivery time and improve material flow for the partly automated, partly manual assembly process. By applying information technology in an integrated way, it should be possible to deliver any custom-designed switch within a day, as against the up to three weeks currently necessary.

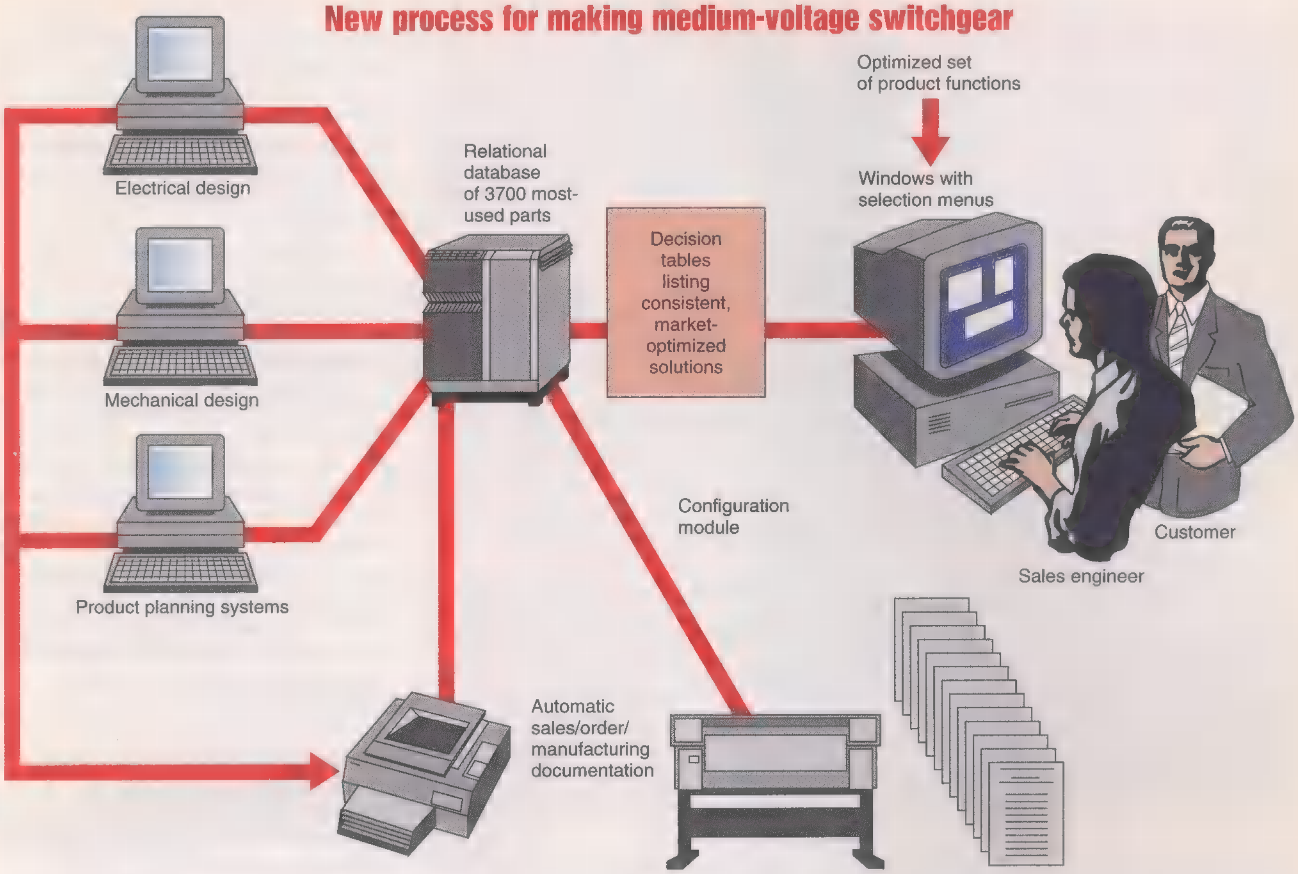
Further significant reductions in time to market are anticipated for the design of new products. Introduction of such products can currently take up to three years from initial conception, and the goal is to reduce this period to well under a year by relying heavily on interdisciplinary design teams. This will mean wide application of concurrent engineering principles, and



Brightly illuminated switchgear casings pass through a quality-control station based on image processing in ABB Stotz's highly automated production line. Casings to be inspected are automatically fed through the station and their images captured with the camera [right].

Machinery for conveying switchgear parts [at right] and several assembly stations [center] are shown in the manufacturing hall at ABB Stotz. A very high dgree of automation was achieved by designing the switchgear for automated manufacture, by integrating design and manufacturing operations, and by overhauling the switchgear design so that the noncustom switches need only a limited number of standardized parts. In the new manufacturing process, people primarily maintain the line and intervene in emergencies (and, of course, design future products and plan production for them).

New process for making medium-voltage switchgear



A new, customer-oriented process for specifying and ordering medium-voltage switchgear is based on functional modeling and standard components. This process, the cornerstone of a new program for production improvement at ABB Mittelspannungstechnik AG, in Switzerland, automatically generates the switchgear configuration needed.

movement beyond CAD into processes making heavy use of computer-integrated manufacturing approaches.

CASE STUDY NO. 2

Medium-voltage switchgear

The process of ordering its product was reorganized from the ground up at ABB Mittelspannungstechnik AG, Zurich, Switzerland, hereinafter called ABB Medium Voltage Switchgears. The company sells switchgear cubicles, which are metal cabinets containing circuit breakers and associated braces, terminal blocks, controls and protective features. Connected to the busbars in a distribution substation, the cubicles are used to switch among the lines running through the substation. ABB Medium Voltage Switchgears produces the cubicles in many varieties to suit a diverse, international customer base beholden to varying electrical standards and systems. In the past, this diversity of needs and products created a design and order-fulfillment process that was often somewhat chaotic.

Sales engineers, to maximize sales, touted a large array of product varieties. This bewildering assortment of product varieties, prices, and not a few incomplete specifications often confused customers. Orders were messed up, being placed, changed, and changed again as additional options were discovered or as specifications were more fully explained. Engineering efforts expended on sales and ordering were astounding. The throughput time for engineering and manufacturing was between 32 and 60 weeks; the on-time delivery rate was just 10–20 percent.

With its mandate clear, ABB Productionstechnik AG, Baden (the Swiss division of the worldwide ABB Production Technology organization), started a project, called Orsita, at ABB Medium Voltage Switchgears to completely redesign the product line and the ordering process. The focus was the interaction with the customer.

All marketing and ordering now center on the customer's requirements. No more confusing and tedious discussions of product components precede a sale. First, the customer specifies what is needed in the switchgear cubicle. Application software based on decision tables and advanced user interfaces guides the customer through this process, right on the salesman's workstation (portable workstations are also used). The system automatically generates the switchgear configuration, based on well-defined standard products and the available options and variations. The customer, armed with a detailed product description that he or she helped to create, is able to approve the sale relatively quickly.

Sales engineers are trained to favor standard products with low prices rather than pushing more expensive custom solutions. The system uses the customer-generated and -approved solution to automatically create design data and data for manufacturing, purchasing, and assembly of the desired medium-voltage switchgear.

This new process is already doing well by ABB Medium Voltage Switchgear's market position and internal procedures. Market share has risen from 24 to 32 percent. Product and business processes are being simplified. Thousands of expensive and rarely used components have been eliminated. Fully 80 percent of the switchgear can now be produced from some 3700 components instead of 50 000.

Overall, the time needed to specify and order a standard (noncustom) piece of switchgear has shrunk from 140 hours to 8 hours, while the engineering personnel in the ordering organization at ABB Medium Voltage Switchgear were reduced from 49 to 37. The investment in labor needed to set the stage for such improvements was 90 man-months over a 15-month period.

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Collaborative environments

Oftentimes in complex design, development, and production projects, the communication and information exchange requirements far exceed the capabilities of ordinary computer-aided design, computer-integrated manufacturing, and concurrent engineering systems and their product-data models. Such activities as project management, team meetings, sales, service, advertising, and accounting similarly require information exchange and support systems. This, then, is where the burgeoning study of collaborative environments comes in.

There are four basic types of collaborative environments, all depending to varying degrees on the enabling parameters of communication, coordination, and cooperation:

- Same time, same place. All the people involved in a project work together in the same room. One class of systems designed to facilitate this kind of collaboration is the computer-supported meeting environment (CSME). It enhances efficiency and quality by adapting specific techniques supporting brainstorming, voting, conflict resolution, and so on. CSMEs also provide templates for preparation and after-meeting assignments (such as minutes and "to-do" lists).
- Same time, different place. The participants in a project work in different offices, regions, or even parts of the world. Enabling technologies range from videoconferencing to shared meeting spaces in a building.
- Different time, same place. This situation is often encountered in project groups working in shifts, perhaps around the clock. The critical requirement in these cases is communication and coordination, so that all team members have the same goals and milestones in sharp focus. Sharing of resources is rarely a problem.
- Different time, different place. This is in many ways the most challenging kind of collaboration. Systems to support it range from e-mail to real "workflow" environments, such as Lotus Notes. In this type of arrangement it is sometimes necessary to find out beforehand if the locations and movements of the various cooperating partners are predictable, and can be exploited to optimize their tasks and usefulness.

Of course, the technical issues are among the most straightforward in this new science. Group dynamics, in terms of social behavior and psychology of teams and human-computer interactions are, however, what largely determine the success or failure of these collaborative environments and their supporting concurrent engineering infrastructures.—*A.J.S., B.S., and K.Z.*

at the University of Karlsruhe. His expertise is mainly in power apparatus and systems, information management, and electromagnetic compatibility.

Bruno Schilli worked at the University of Karlsruhe in the area of standardization of the neutral interfaces IGES, SET, and STEP, and analyzing of enterprises, and wrote his thesis on specification and implementation of product data models. Since 1991 he has been with the ABB Research Center in Heidelberg, currently leader of the group systems integration.

Klaus Zinser is active in the fields of knowledge-based systems in process control, man-machine interaction in complex dynamic environments, and computer-supported cooperative work in engineering applications at ABB Corporate Research.

Manufacturing systems simulated

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Patrick Toole Jr. IBM Charlotte

The effectiveness and efficiency of manufacturing systems can be dramatically altered by the decisions made about their design and their operational planning and control. Yet in industry today, many of these decisions are made by *ad hoc* approaches, unlike the design of the products produced by the systems themselves.

What is needed instead is a careful, systematic analysis of design and operational problems that often plague manufacturing systems. Here, computer simulation can be an excellent tool. This technology can complement the practical know-how of manufacturing personnel with quantitative insights—and possibly even provide insights outside the realm of common intuition and experience. With the added power of desktop computing and user-friendly software packages, a large number of alternatives for decisions can be easily explored, leading to the best choices for meeting system requirements or improving performance. And with this technology, any mistakes are made and corrected computationally, rather than in real life.

A manufacturing system—whether simple or complex—includes any raw materials, tools, operators, and control policies for the operation of the equipment. At the sector level, it also includes flow of material and information through a collection of tools. It can even extend to the procurement, production and distribution networks of suppliers, plants, and distributors. Using computer simulation for modeling and analyzing such systems is helping companies predict and improve a system's performance, as measured by such elements as capacity, cycle time, inventory, utilization, service level, and cost.

Two examples of manufacturing systems simulation performed at the IBM Electronic Card Assembly and Test (ECAT) facility at Charlotte, NC, illustrate how this approach works to improve cycle time and customer service.

COMPLEX LOGISTICS. The ECAT facility produces cards that contain microchips and circuitry used in IBM computers, networking systems, advanced storage devices, monitors, security systems, and other products worldwide. Recently, ECAT entered the contract manufacturing market by supplying electronic cards to other companies. It also provides turn-key service for customers in circuit-board design, parts procurement, prototyping, assembly, manufacturing, and test engineering.

To manage this workload, the logistics environment in Charlotte is complex. ECAT handles orders for over 1400 different assemblies that are made from approximately 8000 distinct components.

Success in providing such huge volumes hinges on two crucial areas. One is the manufacturing cycle time, that is, the time from the release of an order to the production floor to its shipment to the customer. The second is the customer service level, or the fraction of customer orders that were shipped on time as promised. Recognizing that significant improvements were needed in these areas, ECAT turned to simulation modeling for developing and analyzing action plans.

REDUCING CYCLE TIME. A few years ago, Charlotte faced an extraordinary demand for its high-volume token ring adaptor cards used in PCs and workstations. With the level of the ECAT line throughput at that time, Charlotte knew that it would be difficult to make its year-end volume commitments. The problem was to figure out what could be done in the short run to improve the throughput of the line. A researcher from IBM Yorktown and an engineer from Charlotte teamed up to examine what was causing the trouble and make recommendations.

The team developed a simulation model of the ECAT line using a manufacturing line

Defining terms

Buffer: a place where a job is stored between operations.

Level of customer service: the customer orders on a manufacturing system that are delivered to customers on time as a fraction of the total customer orders on the system for a specified period (say, a week).

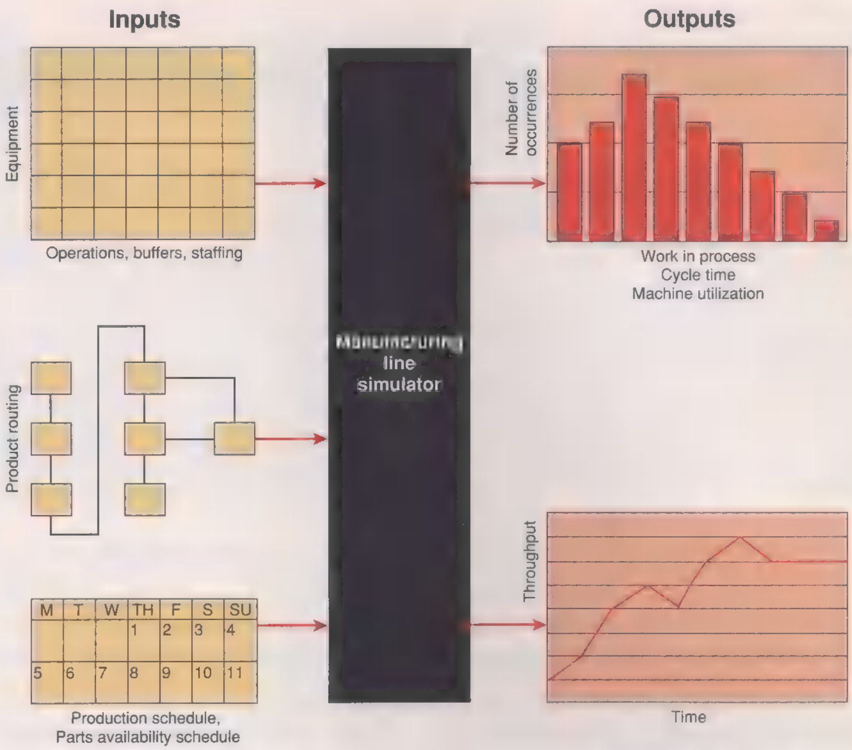
Level of supplier service: the orders a supplier delivers on time as a fraction of the supplier's total orders for a specified period (say, a week).

Manufacturing cycle time: the time from the release of a job to the completion of its processing through a manufacturing system.

Product routing: the sequence in which a job will visit the manufacturing equipment within a manufacturing system for processing.

Protective scheduling: a material requirements planning policy that ensures that materials are on hand a specified time ahead of when they are required for production.

Sector-level manufacturing system: a physical and logical collection of manufacturing equipment interrelated through flow of material and information.



A manufacturing simulator's inputs identify the operations, buffers, and staffing requirements for each piece of equipment, product routings, and production and parts-available schedules. Outputs predict the work-in-process, cycle time, machine utilization, and throughput.

simulator [see top figure, at right]. This kind of simulator is a computer program that enables a user to develop a model of a manufacturing line, simulate its operation using the model, and analyze the results from the simulations—all without writing computer code in a programming language. Today there are many commercial manufacturing line simulators on the market [see table, p. 62]. At the time of this example, however, there were only a few available, so the team used one developed by IBM Research.

Information about the equipment, the product routing, and the production and parts-availability schedules were all inputs to the simulator. Using the graphical user interface of the simulator, these inputs could be described and modified easily without programming.

Information such as the production capacity of machines on the line, the duration of various operations performed by different machines on different products, buffer sizes, and the staffing were tabulated. Product routings (sequences of machines performing specified operations on each product type) were described graphically, while production and parts availability schedules were provided in calendars. The output predicted work-in-process, cycle time, machine utilization, and throughput [see top figure, at right].

Key outputs were the line throughput (the quantity of products produced in each time period), a work-in-process inventory (the quantity of products being worked on in the line), the cycle time (the time from release of jobs into the line to completion), and machine utilization (the proportion of time the machines work on products). These results were displayed in bar and line charts.

Within a week, the team had developed a model of the line, simulated it under the operating conditions of the line, and compared the predicted results with the actual line performance. The predictions were within 10 percent of the actual performance, which proved that the model adequately represented the reality. By examining the simulation outputs, the team found that machines working close to capacity could be easily identified as bottlenecks. Typically, these were the component placement machines.

But the type (surface mount vs. pin-through-hole) and the specific group of machines within the type were found to vary with the mix of products loaded into the line. With the use of the model, the bottlenecks were predicted ahead of the actual loading of the line, and suggestions on how to alleviate the problem were generated by the line engineers.

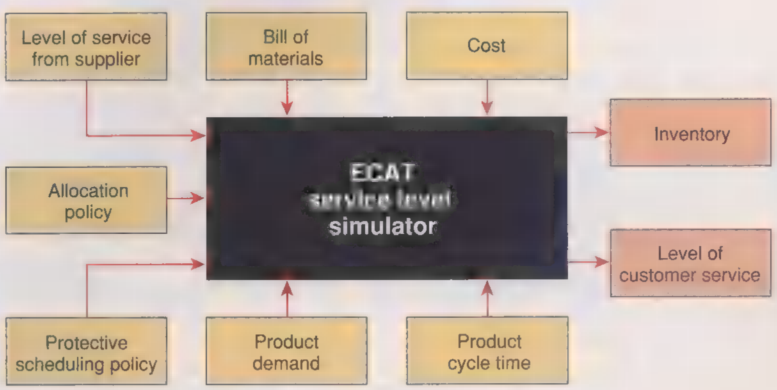
Two proposals recommended changing the number of machines set up to perform specific operations and adjusting their maintenance schedules. These proposals were also modeled, simulated, and verified to improve the line throughput. In this manner, Charlotte was able to increase its output by more than 20 percent and to meet its year-end volume commitments.

There was good news, too, in cutting cycle time. In the portion of the line with surface-mount placement machines for the high-volume token ring adaptor cards, cycle time was halved and work-in-process went down by 37 percent. Also, throughput remained the same when the release rate of products into the line was based both on its overall production capacity (determined through simulation) and on demand, rather than solely on the latter.

Most importantly, Charlotte was sold on using simulation as a way of analyzing and continually improving the performance of the line. ECAT followed this path of improvements and modified the layout of the line based on continuous flow manufacturing principles (that is, the reduction and/or elimination of buffers) and model-based evaluation of alternatives.

Over a one-year period, the sector cycle time was down by a factor of 5, and the work-in-process was reduced by more than 80 percent while the throughput increased about 40 percent. Thus there were clearly significant improvements in all key performance measures.

SMARTENING UP SERVICE. One measure of customer service level at an ECAT plant is the ratio of cards shipped on time to customer orders due each week. Despite the



A service-level simulator was able to recommend effective ways to meet customer demand at IBM's Electronic Card Assembly and Test Facility in Charlotte, NC.

Some manufacturing simulation software

Company	Package	Price in US $	Platforms	Operating systems	Three most significant new features
AutoSimulations Inc. Bountiful, UT	Automod	$15 000 and up	Silicon Graphics, 386/486 PC, Sun	Unix, DOS	Easy-to-use graphical and spreadsheet interface that produces accurately scaled 3-D animated models; manufacturing orientation reflecting logical and physical aspects; accurate statistics that are automatically generated and collected
Caci Products Co. La Jolla, CA	SimfactoryII. 5/Simprocess	$9500 and up	486 PC, Sun, IBM RS/6000, HP 700, Silicon Graphics	Windows, OS/2, Windows NT, Unix	Icon-based, user-friendly interface with no programming; user-defined libraries of modeling elements for business and manufacturing; user-defined report templates
Pritsker Corp. Indianapolis, IN	Factor/ AIM	N.A.	OS/2-compatible	OS/2	Easy-to-use; integrated module of the Factor planning and scheduling system; realistic animations of the operations modeled; hundreds of built-in rules and ability for creating customized rules
ProModel Corp. Orem, UT	ProModel for Windows	$9975	386/486 PC	Microsoft Windows	Design aimed specifically at the manufacturing environment; point-and-click approach to modeling; built-in personal trainer; object-oriented development

decreasing production cycle time and heroic efforts by plant personnel to meet the schedules, Charlotte was not achieving the required level of customer service.

To understand the root causes for this problem and to recommend effective ways to address them, the ECAT management commissioned a task force. It consisted of two researchers from Yorktown, a materials engineer from Charlotte, and two staff members from corporate headquarters involved in the overall ECAT supply-and-demand management process.

Believed to be the main contributors to the problem were the supply performance (service level) of ECAT's component suppliers, ECAT's component procurement policies, and the current production performance.

Over four months, the task force developed increasingly sophisticated simulation models that focused on the inventory and service-level performance of the ECAT plant rather than its production performance. Because the volume of data to be dealt with was orders of magnitude higher than in the previous example, manufacturing line simulators could not be used. Instead, models were developed from scratch in the C language.

Initially, the model developed could perform the simulation for only a single period of one week, and the results were grossly different from the actual performance. The team then developed a model with a simulation capability of multiple periods of one week [see figure, bottom of p. 61].

FOCUS ON SUPPLIERS. One key input to the simulation model was the level of service of the component suppliers. The major elements of the characterization were the percentage of on-time deliveries and the distribution of lateness of the delayed deliveries; these were developed by analyzing their historical performance as well as possible improvements that were believed to be negotiable.

Another important input was the component procurement policy characterized by protective scheduling (a policy of planning for the components to be on hand a specific number of days or weeks before they are needed for production) and other logistics parameters (such as the frequency of orders to, and deliveries from, suppliers and minimum order quantities).

Finally, the policy of allocating available components to different products before they were assembled on line needed to be modeled. The primary outputs from the simulation model were the ECAT level-of-service against the demand for products from customers and the level of component and work-in-process inventory.

The model was validated against actual Charlotte performance with the historical supplier service level and the procurement policy in effect at the time. Then a number of alternative combinations of protective scheduling parameters and supplier service levels were run through the model. For example, the protective scheduling parameters were varied from zero to four weeks in increments of one week. The on-time delivery percentage was either the historical value or 95 percent. The time period by which the delayed deliveries were completed was either the historical value or one week.

Results of the simulation runs provided many insights into how the ECAT service level could be improved and what the impact on inventory would be. For instance, it was discovered that many of the components (those with very high values for unit cost times annual usage volume) had zero or one week of protective scheduling, based on inventory considerations alone. The model predicted that if the level of protective scheduling were changed to two weeks, the service level would be improved by over 26 percent with an additional inventory implication of US $11 million in Charlotte.

Because of the increased ECAT service level, however, Charlotte's customers would not have to carry as much protective stock of Charlotte products and the resulting inventory savings to them were estimated to be $36 million. Other savings due to overtime and premium transportation were calculated to be about $10 million.

After analyzing the simulation runs carefully, the task force made recommendations to be implemented in phases. The first of these was to change the protective scheduling values for those components with zero or one week parameters.

CUSTOMERS BENEFIT. Results of the implemented changes showed up in actual ECAT performance about four months later, because most of these components were high-technology semiconductor parts and had a long procurement lead time (three to four months). On the average, the ECAT service-level improvement for five consecutive months of the year of implementation was about 26 percent over the previous year, just as had been predicted by the model.

The application of simulation technology for solving complex problems in manufacturing systems can be extended further to include the business processes surrounding the manufacturing systems, say, for customer order processing and for business and production planning processes. Exploring the power and potential of simulation technology to address complex strategic and operational business issues thus is one area of current research interest and activity.

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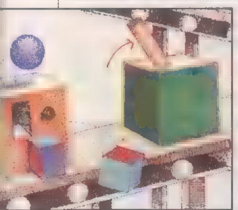
Patrick Toole Jr. is the manager of information solutions at IBM's Electronic Card Assembly and Test (ECAT) plant in Charlotte, NC. He is currently responsible for ECAT's information technology. He has held a number of management positions in manufacturing engineering, industrial engineering, and operations research.

Green products for green profits

As if global competition is not tough enough already for manufacturers, now they must work within growing public concern for the planet's health. Not only are industrial processes being monitored more closely for pollution, but products, increasingly, are expected to be energy efficient, easily recyclable, with minimal use of materials that harm the earth.



The hostile regulatory and "end-of-pipe" remediation approach that characterized environmental concerns in the 1970s, especially in the United States, is giving way to a more cooperative approach between government and industry. More companies are beginning to think green at the design and manufacture stage of a product—an approach that can result in greater profit for both the bottom line and the environment.

In this early stage, as Diana J. Bendz shows, efficiency is often compatible with environmentally preferable processes and products. Farther off, once the "low-hanging fruits" are plucked, argues Brad Allenby in an accompanying piece, changes in company operations and legal infrastructure will be required [p. 64].

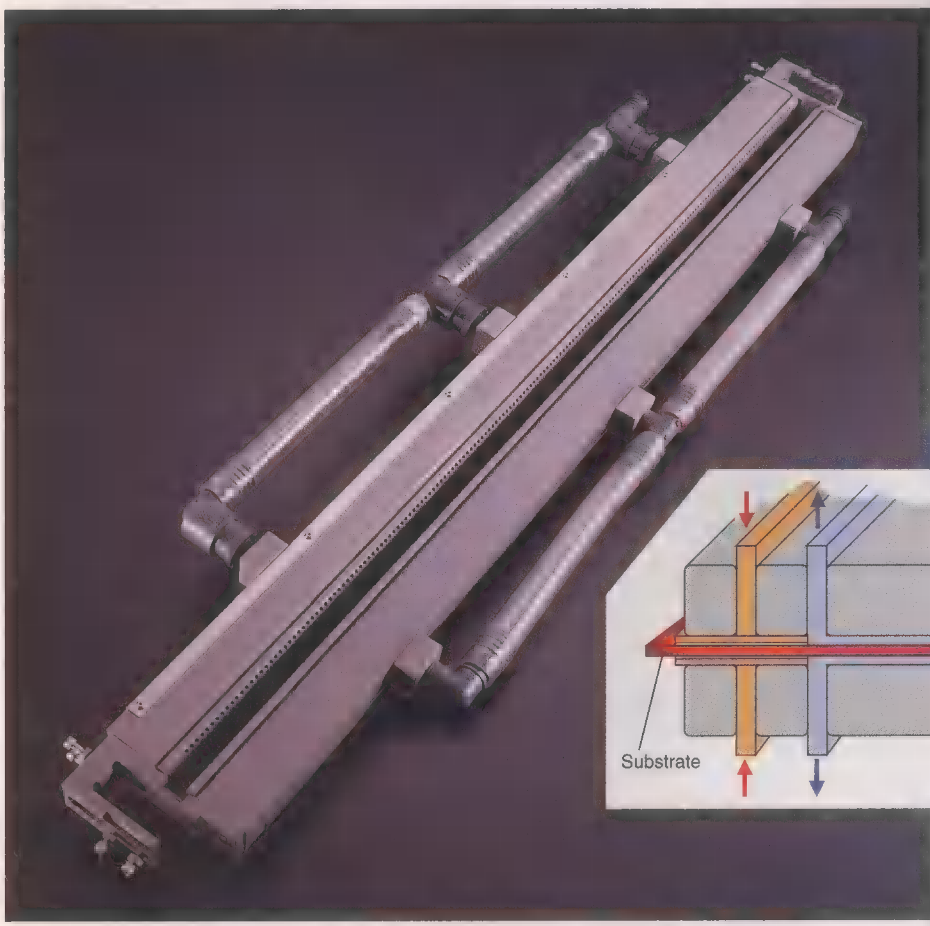
International actions

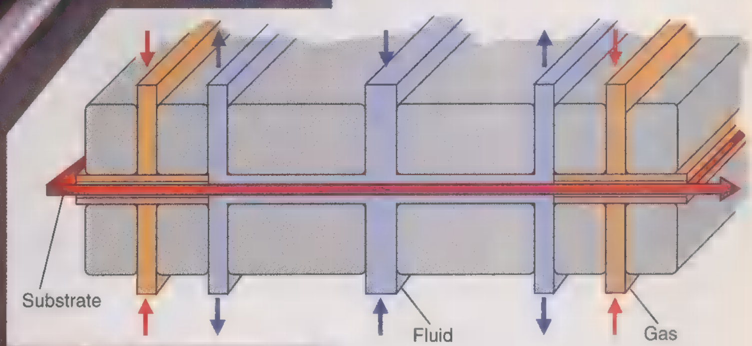
Diana J. Bendz IBM Corp.

A recent Gallup poll of citizens of 24 nations—both developing and industrialized countries—found that a majority considered environmental protection more important than economic growth. It is no wonder, then, that market and legislative pressures bearing on the environment are profoundly affecting the design and manufacturing process, including that of the worldwide electronics industry.

In Europe, many countries already have environmental product-labeling initiatives, and the European Community is developing a policy on green labels. The International Organization for Standardization (ISO), in Geneva, is creating standards for environmental attributes, and draft proposals may be ready early next year. Germany is to mandate in 1994 the collection, reuse, recycling, and safe disposal of used equipment, including personal computers (which, at about 6 million units annually, are among the most voluminous returns). Denmark, France, the Netherlands, and Sweden are considering similar "take-back" proposals. Also in the Netherlands, the largest consumer organization there recently stated that a color TV set should be considered chemical waste and treated as such.

In Japan, energy metrics and year 2000 goals are being set for all classes of information technology products. These metrics will define allowable energy consumption for a piece of equipment as well as a complete enterprise, be it a personal com-





Traditionally, printed-wiring boards are carried on rollers and sprayed with cleaning solvents and water, then blow dried. A compact new fluid-delivery system [below and in photo] reduces wastewater by 80 percent (a boon in drought-prone California) and other solvents, too, by using speeding fluid to cleanse the boards while transporting them. In the photo, a board, or substrate [not shown], moves toward the viewer. The result benefits not only the environment but also throughput and yield. For a year, IBM has been installing the system in many of its facilities and has recently begun selling the process technology.

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puter, an office building, or a factory.

In the United States, the U.S. Environmental Protection Agency (EPA), Washington, DC, being considered for elevation to Presidential cabinet status, has been working with industry to define reasonable environmental goals and facilitate cooperation in achieving them. One result is a labeling program for energy-efficient computers. The EPA's chlorofluorocarbon (CFC) label mandate requires labeling of all products made with CFCs, with an ultimate goal of complete phase-out. So-called "take-back" laws are in force in seven states that require return and recycle programs for batteries.

All these examples are responses to sentiments long in existence and now documented in the Gallup survey. The economics of such mandates cannot be ignored in highly competitive global industries, and so design-for-the-environment initiatives are growing. The electronics industry, a leading manufacturer worldwide, is establishing an exemplary leadership position in "green" compliance and progress.

Design-for-environment (DFE) programs call for the careful inclusion of environmentally safe attributes in the early design stages of new products, as opposed to re-engineering them late in the product cycle. These attributes are being defined every day by global legislators, by technology advances, and by customer perception. So DFE includes monitoring of worldwide events and providing appropriate engineering responses.

AT&T Co. is trying DFE within several business units. At IBM Corp., the corporate-wide Integrated Environmental Design program calls for ■ concurrent focus on product and process design. Pitney Bowes Inc., Stamford, CT, has implemented ■ Design for Environmental Quality program. Apple, Digital Equipment, Hewlett-Packard, Intel, Motorola, Siemens-Nixdorf, and Volvo have similar efforts, recognizing the economics of tackling environmental concerns at the earliest design stages.

"These programs are also proving to be economically sound, emphasizing conservation of materials and energy, thereby enhancing profit potential," observed Peter R. Schneider, IBM's vice president of development and environmental affairs.

For example, many of the technologies that formerly required processing with CFCs now are produced with water-based systems. The re-engineering cost may have been high in some factories, but the resultant process is less expensive to operate. Recycling efforts can reduce the volume of raw materials, ■■ well as the cost of disposal. Source reduction also cuts the cost of using raw materials and so can reduce the associated problems with their extraction. So-called "snap technologies" are green alternatives to metal fasteners or chemical bonding (the latter as in the many electromagnetic compatibility shields that adhere to plastic cases). These molded-in snaps lower process costs and also facilitate recycling efforts because of the all-plastic uniformity of the materials and ease of disassembly. IBM has designed a "green" PS/2 computer that uses primarily one polymer and snaps together, to ease disassembly and recycling.

Maximizing the use of recyclable materials opens up revenue possibilities at the end of a product life cycle. Component reli-

Green design

As part of the new beneficence toward this burdened planet, more engineers are adding "Design for Environment," or DFE, to their lexicon. This requires that environmental objectives and constraints be an integral part in product and process design, and in the selection of materials and technologies.

The focus is on the design stage where for many items, most, if not all, of the life-cycle environmental impacts are established—explicitly or implicitly. Data in a recent report from the U.S. Congressional Office of Technology Assessment estimates that manufacturing operations in the United States account for more than 50 percent of wastes, about 11 billion tons annually, including much dilute wastewater.In contrast, less than 2 percent is contributed by the highly publicized household and municipal solid waste.

Within ■ company, design for the environment encompasses two broad activities. One is all-pervasive. It might include green accounting practices that consider environmental costs, and "standard components" lists of internally approved and banned components. (An example of the latter might be open relays that require ■ chlorinated solvent to be cleaned.) Contract provisions, and customer and internal specifications, can give priority to recycled materials (when they meet all requirements) and to the use of green technologies and materials whenever possible.

The other activity is product specific, in that design for the environment should function as a module within the existing product realization processes. This involves the creation of software tools and lists, analogous to those modules used in, for example, design for manufacturability, design for testability, or design for safety. It means not only recyclable products but ones that operate more effectively during their use.

Data and methodological deficiencies abound and the challenge is great. But experience at such companies as AT&T, Digital Equipment, Hewlett-Packard, IBM, Motorola, Siemens-Nixdorf, Volvo, and Xerox indicate that it can be done. AT&T Co., for instance, is involved in several activities. It is testing a draft DFE practice in several business units. The company is also baselining the environmental attributes of ■ telephone at different stages of its life cycle to determine where meaningful improvements in environmental impact can be achieved. Finally, it is developing software tools to uncover environmentally preferable design solutions.

In Sweden, AB Volvo, Göteborg, already has developed a relatively simple strategy, which uses "environmental load units" to inform materials selection. In Germany, Siemens-Nixdorf has devised an "eco-balance" system, which reflects both environmental and economic requirements in design. Xerox Corp., Stamford, CT, is already a world leader in designing products for refurbishment. In Japan, the Ministry of International Trade and Industry and others, including NEC Corp., Tokyo, are fashioning the concept of an "eco-factory," with environmental performance to be optimized by data-intensive design, product tracking, and product recycling.

Broader efforts include a series of white papers by the DFE task force of the American Electronics Association, Santa Clara, CA. The Microelectronics & Computer Technology Corp., Austin, TX, brought companies together with the U.S. Environmental Protection Agency and the national laboratories to examine the environmental impact of a computer workstation. The resulting study is valuable not only for its technical findings but for the gaping holes in data and methodologies that are identified. A life-cycle environmental assessment methodology for substances is being developed by the Society of Environmental Toxicology and Chemistry.

Implementing DFE is increasingly critical if companies want to be globally competitive, and it is something a company can begin to some degree now. But attempts to implement green design so far indicate that private firms, acting alone, cannot do it in a systematic way. Governments, preferably acting in concert, will need to create some important tools for the job. These tools might be viewed as a DFE infrastructure and could include a general database and a revamping of common priorities .

In the future, once the "low-hanging fruits" are plucked, changes in company operations as well as in the technical and legal infrastructure will be required if firms are to create product lines with minimal adverse effects on the environment and their own bottom line.

Before large numbers of firms remanufacture their products, though, the many existing legal structures that apparently have little to do with the environment may need to be changed. For example, many consumer protection and government procurement laws currently discriminate against refurbished products. Governments also must develop and implement policies creating a rational system of incentives. International cooperation is also desirable here. It does little good for one country to have stringent requirements, while another relaxes pollution standards. *—Braden R. Allenby*

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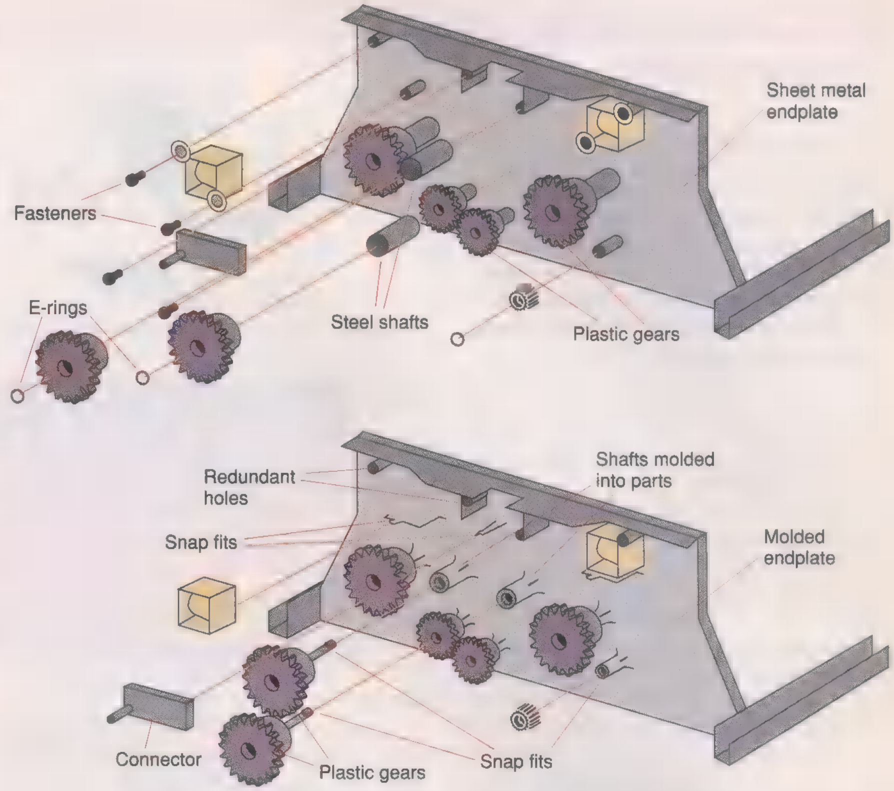
ability, a fundamental design goal in the electronics industry, supports the re-use of such parts in new or refurbished equipment, again saving raw materials, manufacturing costs, and time.

Other process innovations contribute to environmental soundness while boosting manufacturing efficiency. Texas Instruments Inc., based in Dallas, using money from the Department of Defense's Advanced Research Projects Agency (ARPA), Arlington, VA, to develop new small-batch wafer-processing technologies, found considerable savings in raw materials and energy usage.

Over the last year, IBM has been deploying an innovation within its facilities for processing printed-wiring boards. Small volumes of high-speed fluid serve to both transport and clean the boards. The process saves about 80 percent of the water wasted in the traditional method of using rollers to transport and sprayers to cleanse the boards. The equipment is also more compact and results in better throughput, higher yields, and lower costs.

REMANUFACTURING. Xerox Corp., Stamford, CT, estimates that its environmental programs already save the company more than $100 million annually. It has the backing of the highest levels in the company. Paul Allaire, chief executive officer of Xerox, has said that even without the public pressure to be "proactive about protecting the earth... there remains a compelling reason for business to do the right thing: it's the safest and surest way to long-term profitability."

One initiative at Xerox seeks such complete reuse or recycling of business equipment products that no material need be taken to a landfill. Whether this can be done economically on an industrywide scale is as yet uncertain—as is whether customers will pay "new product" prices for rebuilt products, even if they work as well as when new.

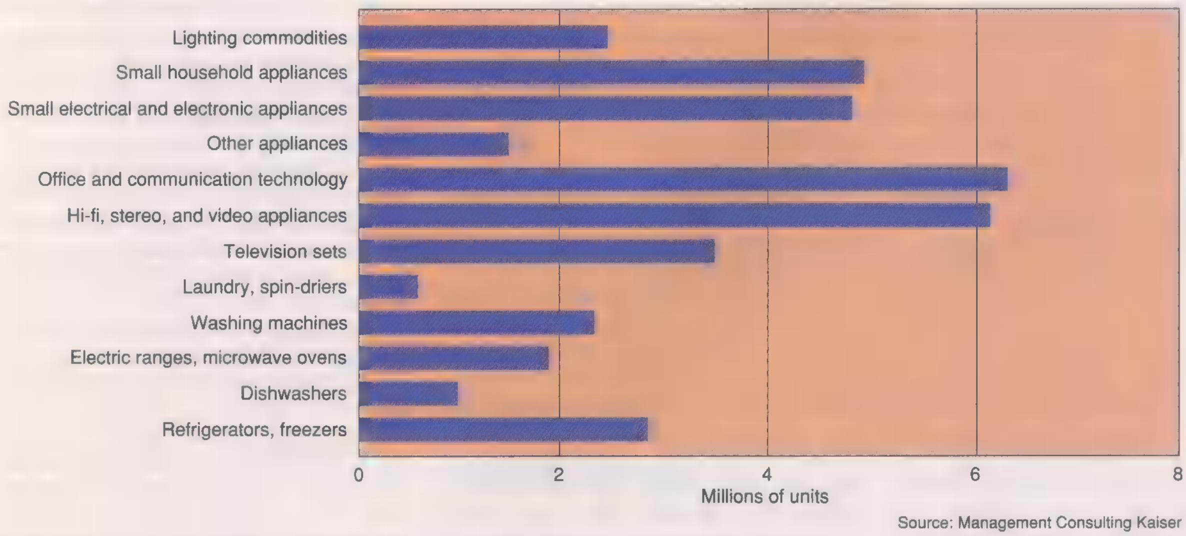


Xerox engineers redesigned the feed head of the 5028 copier to facilitate disassembly and recycling. The original design used separate fasteners, screws, e-rings, steel shafts, plastic gears, and sheet metal. The new design uses compatible materials to decrease hardware scrap, and it snaps apart to speed disassembly.

Remanufacturing involves disassembling a machine, replacing worn-out parts with new, remanufactured, or used components. The machine is then cleaned and tested to ensure it meets quality and reliability criteria for a newly manufactured machine, according to a paper by V. Berko-Boateng and several Xerox colleagues in the May 10–12, 1993, proceedings of the IEEE International Symposium on Electronics and the Environment.

To meet the challenge of zero waste material, they acknowledge the following issues must still be addressed:

- Product simplification.
- Design for disassembly rather than merely for assembly.



In Germany, a new law that goes into effect next year mandates the recycling of household appliances, including hi-fi, stereo, and video appliances, television sets, washing machines, dishwashers, and refrigerators. Items estimated in the millions are already being collected each year for recycling.

Some labels for environmentally preferred products

Governments and nonprofit organizations are promoting the use of ecolabels to identify environmentally preferred products for consumers. More stringent warning labels such as this one from the Environmental Protection Agency in the United States may be the alternative for manufacturers using hazardous materials.

MILJÖMÄRKT

Nordic countries

European Community

ENVIRONMENTAL CHOICE · CHOIX ENVIRONNEMENTAL

M – Official mark of Environment Canada
M – Marque officielle d'Environnement Canada

Canada

WARNING
Manufactured with CFC-113 and/or 1,1,1,Trichloroethane; these substances harm public health and environment by destroying ozone in the upper atmosphere.

U.S. Environmental Protection Agency

GREEN SEAL

Green Seal, Washington, DC

Umweltzeichen
weil schadstoffarm
Jury Umweltzeichen

Germany

ちきゅうにやさしい

Japan Environment Association, Tokyo

- Reducing material diversity.
- Maximizing the useful value of all materials.
- Incorporating recyclable materials, especially plastics.
- Developing a consistent recycling strategy, including inventory management and testing of used components.

A matrix of design principles developed by Xerox shows that many design-for-assembly principles are congruent with those that underlie disassembly and asset recovery management.

ENGINEERS' ROLE. The electronics industry is in a unique position, not only because of the technical solutions already implemented, but because of its extraordinary engineering talent. Its engineers will therefore play ■ critical role in implementing the popular concept of "sustainable development."

Recently the American Association of Engineering Societies, Washington, DC, issued ■ formal statement, "The Role of the Engineer in Sustainable Development," which carefully defines the concept and what additional considerations those in the profession will need to take note of in their jobs.

Sustainable development, for instance, is defined as "a form of development or progress that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Although today's engineers often have the know-how for environmental solutions, academic institutions have ■ major role to play in supplying tools and information to optimize these solutions. Shirley Fleishmann, of Grand Valley State University in Allendale, MI, has integrated the environmental theme into the undergraduate engineering curriculum there, rather than create additional courses. This is in accordance with the industrial philosophy that the theme must be integrated into everyone's thinking and work product.

The most significant results perhaps will be realized in years to come, because teachers of elementary and secondary science classes are instilling a respect for the environment in their students, providing the all-important integration of that concern with other scientific concepts. Schoolchildren in various regions of the United States, for instance, are monitoring rainfall in an acid rain science project conducted over the Internet electronic network.

Industry's products can also influence environmental progress. Industry provides and has available information technology tools that at the very least enable rapid information exchange. Tools are also being developed, moreover, to access pertinent databases, optimize design choices, and manage process chemicals to minimize utilization and waste. Many companies are devising internal systems to help environmental decision-making.

The industry has been cooperating on green technology concerns under the aegis of groups like the American Electronics Association, Santa Clara, CA, and the Microelectronics & Computer Technology Corp., Austin, TX. Much difficult work remains to be done in this nascent field, but the benefits can make sound sense to businesses now, while at the same time protecting the planet's assets for the generations of the future.

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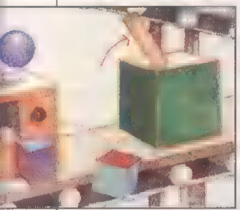
The economic angle

Manufacturing, like any human activity, is carried out and evolves within a larger framework, in this case, a corporation, which itself is shaped by larger social, cultural, political, and economic forces. Over the last decade or so, manufacturers have remade traditional mass production (or have seen it remade) into a tighter, more efficient, and more integrated enterprise known as lean production. Yet already, running before the changing winds of competition and globalization, manufacturing is metamorphosing into something else again. It is probably too soon to tell precisely what new paradigm will arise. But in the articles that follow, three top U.S. experts consider the factors that are shaping this emerging enterprise, and speculate about its nature and direction.



Beyond lean: an essay

Michael G. Borrus and Stephen S. Cohen
Berkeley Roundtable on the International Economy

It is no longer sufficient—or even interesting—to say that the economics of manufacturing are changing fundamentally, and at a pace not seen in the United States or Europe for generations. Today, most of our discussions are devoted to tracing out the complex engineering and organizational questions raised by this sweeping change.

Most large manufacturers are radically restructuring their entire production process—from design through assembly and distribution—and are dragging their diminishing battalions of suppliers into the process along with them. In the current vogue, some are even drastically re-engineering their organizations, eviscerating functional distinctions that have held for decades, and pursuing the Holy Grails of faster cycles, improved productivity, and higher quality.

The watchwords of this shift, popularly associated with Japanese manufacturing innovations collectively dubbed "lean production," are familiar: flexibility, total quality control, just-in-time logistics, total asset productivity, reduced cycle times, concurrent engineering, and continuous improvement. These powerful emblems make it tempting to conclude that traditional mass production has been superseded—most fully in assembly, partially in process industries—by a single new kind of organization invented in Japan and now diffusing throughout the advanced countries.

We disagree. Lean will not be the last word. National differences in corporate strategy and organization will necessarily extend right through production. The very origins of the lean system in Japan reflect this; after all, when Japanese firms found themselves inventing it, they were actually trying to imitate such mass producers as Ford Motor Co. and the Aluminum Co. of America (Alcoa). And just as the best mass producers did not become the best lean producers, it is not clear who will become the best "post-lean" producers—it is not even clear exactly what post-lean will be. The prospect is for several variants.

Lean production was originally called "fragile" production—limited in scale and resources, and therefore competitively vulnerable. The old term suggests the specific conditions out of which it arose. With heroic brevity, we would list them as follows:

- Market protection to create "launch space" (favorable initial sales) and ensure smooth growth paths, thus providing critical insulation for fragile practices needing lots of it.
- Low- or even no-cost capital, critical for long-term strategies and steady expansion.
- Social harmony of interests among government, big business, and the rest of society.
- Short, secure, and tight supply lines, as well as direct and continuous face-to-face communications up and down the production process.

In short, even an apparently concrete phenomenon like production organization must be understood in a much wider context: national political economies and the market logics they generate.

Leading firms in Japan now find themselves obliged to change their hugely successful systems in response to new circumstances. Structural shifts in the country's financial and asset markets have forced its producers to confront capital costs and return-on-investment requirements that resemble those of their European and U.S. competitors. At the same time, increased protection of markets abroad and escalating costs at home have obliged Japanese companies to locate production—and not just assembly—abroad. Along with these shifts come new difficulties calling for new solutions.

For example, a key part of Japan's lean system is the willingness of executives, engineers, and even workers to meet continuously, typically on their own time (the "blue suits at night" factor). This is an ethic and communications system that is proving difficult to transfer to other cultures.

Meanwhile, as we have seen, U.S. and European firms are reorganizing to change over from traditional mass production to lean approaches. In the United States, traditional mass production relied on two sets of linkages, one within firms, the other between them. The first linkage was classic hierarchical, bureaucratic organization and communication: information moved up; decisions came down, often in writing, slowly and expensively.

The second linkage consisted of market interactions. These are supposed to be quick and cheap (example: order 500 No. 2 yellow pencils and get a good price). But this kind of linkage depends on a very high degree of specificity: one has to be able to identify the product (or service) and its price with no ambiguity and little complexity. For that to be possible, the products generally must already exist. Absent that ultimate condition of specificity, the market transaction becomes one of detailing (usually in writing) a mass of specifications, threatening to turn the transaction into a morass of arrangements and agreements, possibly involving protracted negotiating sessions among teams of lawyers—the polar opposite of fast and cheap. As IBM Corp., General Motors Corp., and others have discovered, this danger imparts an enormous bias against change.

Lean production simplified the hierarchy and—through cross-functional teams that included suppliers and, often, customers—increased specificity, a distinct improvement. By contrast, the emerging successors to lean production will innovate by refashioning the many linkages that characterized mass-production organizations.

Groping toward that succession, U.S. companies are currently changing their structures, boundaries, sizes, and shapes. This is not just "downsizing" *à la* GM, jettisoning people and resources so that what is left corresponds to smaller market shares; it is not just an effort to create entrepreneurial initiative, *à la* IBM; and it is not just a kind of Brownian motion. Perhaps it is purposeful Brownian motion, or *tattonnement*, as the French-Swiss economist Léon Walras called adjustment processes.

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U.S. firms are attempting to find and implement new linkages among their activities—and not just any linkages, but ones capturing the benefits of the lean approach, while accommodating the imperatives, constraints, and paths perceived as open in a U.S. environment. European companies have embarked on analogous trajectories.

Linkages within organizations will no longer involve iterative passages through multiple levels of hierarchy; they will be interactive and face-to-face. The most challenging linkages will be the ones between companies. Virtual integration across companies, often within informal groupings, will create something between administration and the market, permitting casual interactions and less-than-perfect specificity in product and price.

We expect that after completing one or two rounds of shop-floor reorganization, U.S. companies will probably focus their energies on transforming white-collar jobs in administration, engineering, sales, and service. Firms will rely heavily—far more than have the Japanese—on technology, particularly information technology. A preview of its role can be found at such companies as Hewlett-Packard Co., where production and manufacturing applications are driving corporate data-network traffic up by 20 percent a month and now account for 70 percent of the total. These percentages are far greater than those characteristic of the company's commercial or administrative users.

With a keen sense of urgency, U.S. and European firms are groping toward a successor to 'lean' manufacturing, one that keeps the strengths of the lean approach while accommodating national imperatives, cultures, and constraints. White-collar jobs in engineering, administration, sales, and service will be strongly affected, as information technologies further transform manufacturing and production.

Such companies are using network technologies not simply to improve existing processes but, more fundamentally, to recast the organization. Network-facilitated transactions are helping to restructure sequential design processes into concurrent engineering, to draw suppliers into real-time product development, to tap and integrate know-how in remote locations (both inside and outside firms), and to reconstruct logistics throughout entire industrial sectors.

Our hypothesis, then, is that U.S. firms are not reorganizing themselves by copying or adapting the specific linkage structures that defined lean production in the Japanese environment, even though their efforts are often promoted and conceived in that way. Rather, U.S. firms are attempting to develop new linkages that define alternative production organizations. Information technology will serve to rearrange linkages among firms and their suppliers, partners, and customers, as well as between design, engineering, manufacturing, assembly, distribution, and service operations—regardless of where they may lie relative to the boundaries of the firm. Ford, for example, recently announced a major initiative to move design out of specific geographic and corporate locations and into its companywide telecom network.

Network-supported transactions will overturn the conventional economics of production. Increasingly, networking configurations will come to embody more and more of the production process. Some of these network-supported relationships will be "agile," in the current vogue—capable of being rapidly connected and disconnected as production needs change. But some of these relationships, perhaps the vast majority, will be enduring—that is, capable of supporting the long-term and interdependent sharing of data and know-how that underlies technological advance. Network flexibility will then be central to competitive advantage, for that will shape both the ability of a firm to experiment with new forms of organization, and the knowledge it accumulates along the way.

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Stephen S. Cohen is a professor at the University of California at Berkeley and codirector of BRIE. He has extensive experience as an international economic consultant, having worked abroad with the Organization for Economic Cooperation and Development, the United Nations, the governments of France and Denmark and the Prefect of Paris, and the presidents of Colombia and Spain. In the United States he has consulted with the White House, the Joint Economic Committee of the U.S. Congress, the House Committee on Banking, Finance and Urban Affairs, the Senate Committee on Governmental Affairs, and the Department of Commerce, as well as with various U.S. and European companies. He is the author or coauthor of a number of books and articles, including Manufacturing Matters: The Myth of the Post-Industrial Economy *(with John Zysman, Basic Books, 1987).*

Technology, people, and management

Paul M. Swamidass Auburn University

Pity the business executive trying to fathom the conventional wisdom on manufacturing. Many experts, bowing to the Japanese successes of the 1980s, argue that investment in advanced manufacturing technology is the bedrock of competitiveness. On the other hand, a widening circle of pundits espouses a seemingly antithetical notion: that personnel and management matter far more than technology to success in manufacturing.

Both ways of thinking, it would appear, cannot be true. So what is a manufacturer to believe? Those expecting a simple answer may be disappointed to learn there are elements of truth in both.

To compete in future world markets, manufacturers will increasingly have to turn to technologically sophisticated techniques of manufacturing automation in order to obtain great flexibility in product variety and manufacturing volume. These techniques will not work, though, unless supported by appreciable shifts in organization and human resources.

Take the automotive industry. It is one of the most important arenas of international competition and the proving ground for many advanced manufacturing techniques. "The U.S. automobile industry learned a hard lesson about the need to coordinate technology strategies with manufacturing and human-resource policies," wrote the authors of the acclaimed book *Made in America: Regaining the Protective Edge* (MIT Press, Cambridge, MA, 1989). "The disappointing experience of General Motors with highest-technology plants demonstrated that simply investing large amounts of money in new hardware is not the answer. Technology strategies that are tightly integrated with the manufacturing work force, the organizational design, and human-resource practices work far better." [see To Probe Further, p. 85]

Before dismissing technology outright, however, it would be wise to weigh the evidence, gathered over many decades, that improvements in process technologies lower manufacturing costs and raise product quality. In a study I did recently with the National Association of Manufacturers in Washington, DC, I found that in the average manufacturing plant conforming to selected industrial classifications (SIC 34 through 39), the sales per employee was US $141 000, while in plants using certain modern technologies it was nearly $200 000. The point is, technology is a proven source of productivity growth in manufacturing.

ANY VOLUME. Over the past 20 years, manufacturing automation technology (also called "hard" technology) has undergone a metamorphosis comparable in magnitude to

Henry Ford's introduction of the assembly line some 80 years ago. The proliferation of microprocessors and of computers based on them has stood the meaning of manufacturing automation on its head.

The term once referred to the inflexible technology employed in high-volume, low-variety, and low-cost manufacturing. Today, thanks to computerization, manufacturing automation means increased quality *and* flexibility: it has reduced the time and cost of switching manufacturing from one model or product to another, thereby enhancing the capacity to roll out a wider variety of products without penalty. The benefits are many and obvious: because manufacturers can now appeal to a wider range of customers, they have more avenues for market growth, to name just one.

Manufacturing technology or hardware is made flexible through embedded, reprogrammable microprocessors that can be controlled by computers at the site or at a remote location. This local intelligence has permitted the automation of many decisions and operations that only people could handle 20 years ago. Machines can mimic human operators with the aid of vision systems, embedded expert systems, and decision models based on artificial intelligence. In fact, machines can be almost as adaptable as a person and are making the operators at the lower echelons more and more redundant, even in low-volume production.

DUMB AUTOMATION. Flexibility embedded in new manufacturing technologies is worthless unless it can be exploited by the organization—in other words, by the people, manufacturing techniques, and management surrounding it. Otherwise, the resulting automation is "dumb." In dumb automation, a flexible, advanced technology replaces an inflexible one, but inherits all the people, procedures, and organization used in running the old technology.

Countless studies have shown the ineffectiveness of dumb automation. Michael E. Porter, writing in last year's September/October issue of the *Harvard Business Review,* emphasized how important it is to tightly couple new manufacturing technologies with the surrounding organization. A "physical asset such as a new factory may not reach its potential level of productivity unless the company makes parallel investments in intangible assets such as employee training and product redesign," Porter warned.

Complementing the changes occurring in the hard technologies are advances over the last 15 years in management techniques (also called soft manufacturing technologies). Tighter coupling between equipment, people, and the organization requires greater interdependence among the elements of the organization, as the following examples illustrate.

First, the flexibility implicit in modern automation technology cannot be effectively exploited with outdated work habits and procedures. Rigid work rules for operators imposed by an old manufacturing culture or idiosyncratic union contracts will negate some or all of the benefits of modern technology. Flexible work rules, cross-trained workers, and teams of workers given more responsibility ("empowered") are necessary to help new technology succeed.

Second, the organization, the material and information flow, and the role of management in factories employing new technologies must all adjust. If they do, benefits can be substantial. Flexibility in hard technology means orders can be accepted for smaller lots, the product line can be more varied, newer models can be launched more often, the cycle time for manufacturing can be shortened substantially, inventory of all kinds can be reduced, and so on.

A firm that does not seize these opportunities opened up by new technology is not ready for it and may never enjoy its benefits. One sad instance of this kind of misfortune was General Motors Corp.'s several- billion–dollar investment in modern automation technologies in the 1980s. As numerous business magazines noted in articles in 1987 and 1988, the huge investment had very little impact on the overall success of the enterprise, as gauged in terms of profitability, maintenance of market share, or customer satisfaction. In his book *Achieving the Competitive Edge Through Integrated Technology Management* (McGraw-Hill, New York, 1991), Gerard H. Gaynor describes GM's experience as a tragedy.

A note on investing in modern process technologies: it must be done selectively. Those chosen must fit with the rest of the organization and with its core competencies. For example, if the manufacture of certain parts and components requires new technologies well outside the company's core competencies, then those parts and components should be acquired from another firm ("outsourced").

As James B. Quinn noted in his book *The Intelligent Enterprise: A New Paradigm* (Free Press, New York, 1992),"Many large manufacturing companies (like Sony, Nike, Honda, Apple, Matsushita, Polaroid, Liz Claiborne, Genentech, or IBM) initially succeeded" because "they purposely invested in limited amounts of plant and standard equipment, [and] produced as few components internally as they reasonably could." Conversely, in GM's much-criticized approach, the vast majority of components are fabricated internally. However, GM is now backing away from this approach.

Successful integration of modern manufacturing technologies can also have benefits beyond flexibility. To successfully cut prices each year, and yet remain profitable, manufacturers are turning increasingly to the use of modern technologies as well as new ways of managing the organization and its people. The cost of materials can account for more than 50 percent of manufacturers' expenses, so suppliers have come under heavy pressure to show steady price reductions. A top GM executive, José Ignacio Lopez de Arriortua, before leaving the company earlier this year and being accused by his old employers of industrial espionage, attracted much public attention by demanding double-digit price cuts annually from suppliers. Similar cost-cutting practices are now common at Allied-Signal, IBM, Dow Chemical, and other companies. Suppliers who cannot or will not meet these demands lose their established customers to competitors who can.

Flexibility embedded in new manufacturing technologies is worthless unless it can be exploited by the organization—the people, manufacturing techniques, and management surrounding it. This was a hard and expensive lesson for General Motors Corp. in the 1980s, which spent several billion dollars but saw little improvement in profitability, maintenance of market share, or customer satisfaction.

In summary, modern, flexible manufacturing technologies will pay off if they are tightly coupled with a surrounding and complementary flexible manufacturing environment. It is a misleading overstatement to say technology is not important, but it is similarly simplistic to magnify the importance of personnel and organization at the expense of technology. Manufacturers who have bought into advanced technology tightly coupled with an adaptable team of people and management will be better poised to compete against those who neglect to invest in advanced manufacturing technology.

Smarter workers and management are no substitutes for advanced manufacturing technology; neither can technology substitute for good workers or management. Each has a unique, essential role. When all three come together in the right mix, we have the winning combination known as the competitive manufacturer.

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Helping manufacturers do better

The U.S. Agricultural Extension Service, established in 1914, catalyzed the growth of farming in the United States. A boon to those running small farms, it provides information on the latest agricultural technology and local agents to help farmers solve individual problems. Now, worldwide, similar "extension" services are being provided to small and medium-sized manufacturers. Japan has the most comprehensive network of services, sponsored by central and local governments. In the United States, Federal government support is beginning and some states have launched ambitious programs, often in cooperation with state university systems. Several European countries have also put support programs into place that focus on the small and medium manufacturer as key to regional economic success.

Japan looks after the little guys

Philip Shapira Georgia Institute of Technology

For lack of some prohibitively expensive equipment, the 11 engineers at Maruha Electric Co. were stymied by an electrical noise problem in a computerized solenoid control system. So they contacted their local Kohsetsushi technology center in Nagoya, Japan. The engineers there, using the center's own equipment, soon found the answer.

Likewise, when Towa Denki Seisakusho Co., a small supplier of marine components, needed a bar code system to identify boxes of frozen squid, it called in engineers from its Kohsetsushi in Hakodate, who quickly helped the company develop the technology. (Kohsetsushi, incidentally, is an acronym for *koh*, public; *setsuritsu*, establishment; and *shikenjo*, testing laboratory.)

Japan's Kohsetsushi are government-sponsored technology centers, with large engineering staffs, that serve as free or almost free resources for companies with 300 workers or less. They are part of a system that helps small firms to narrow the technology gap with their larger competitors and to contribute more effectively to the country's economic and technological development. There are drawbacks to the Kohsetsushis, though. They do not always address the nonengineering needs of firms, and they tend to be hierarchically managed with little local initiative and entrepreneurship.

Ishikawa Industrial Research Institute (IIRI) is one of 170 Kohsetsushi created since the 1920s. Its home is Kanazawa, on the western coast of Honshu, Japan's largest island. As a comprehensive technology and testing center, IIRI assists the area's small and medium-sized manufacturers in modernizing and developing their technological capabilities.

Like other Kohsetsushi, IIRI is funded largely by local government, with further support from the central government. A staff of just under 100 engages in R&D, technical guidance and consulting, testing and analysis, the provision of information, training, and other support activities, all for local small industry. Some 3000 analytic projects are completed each year, at no or nominal cost to the client. IIRI also takes part in joint research projects with local companies and universities, and pursues government-sponsored research on topics relating to regional industries.

The Kohsetsushi centers are supplemented by a range of other local and regional technology and industrial support facilities. Near IIRI, for example, in an industrial promotion zone planned as such, are several related organizations. Prefectural centers house industrial associations, and other facilities serve the region's textile, machinery, metalworking, and electronics sectors. There is a center for software training and development and another for promoting indigenous industry. One prefectural center is responsible for training, networking, information services, industry seminars, and making advanced equipment available to small companies.

In addition, on the prefectural and national levels, still other programs offer the smaller manufacturer favorable loans, credit guarantees, equipment-leasing assistance, and tax incentives for new technology investments. Public and quasi-public agencies sponsor numerous schemes for developing regional technology, as well as projects aimed at stimulating the exchange and diffusion of technological information among small firms.

SMALL IS VALUED. Esteem for the small manufacturer has risen steadily in Japan since the 1950s. Today, 870 000 of them employ three-quarters of Japan's manufacturing workers and produce more than half of the manufacturing value added.

These companies are very varied. About half are workshops with at most three workers, while the rest employ 4–299 people. Many of the smallest are engaged in traditional crafts, while other small firms are labor-intensive operations, producing simple components or carrying out relatively routine tasks for larger companies. Some are labor-only subcontractors, with no equipment of their own. But a large and growing segment is directly involved in modern manufacturing.

In technological terms, the gap between small and large firms is far slighter in Japan than in the United States. Almost 50 percent more small Japanese than small U.S. manufacturers use numerically or computerized numerically controlled machine tools, and they use more than four times as many advanced machining centers and robots [see table, p. 73]. Worker training—essential to the proper use of new technology—is also more common in small Japanese firms.

These hundreds of thousands of small, flexible, technologically proficient manufacturers, helped by various government programs, are a source of high-quality inputs and potential technology enhancements to large companies, like Toyota Motor Corp. or Matsushita Electric Industrial Co. Close, long-term relationships with large customers have given the small subcontractor the confidence to invest in new technology, workforce training, and ongoing product and process improvement.

Contracting in Japan is typically organized in a pyramid, with large manufacturers at the top supplied by lesser firms in two or more lower tiers. The large companies drive the smaller to modernize by exacting ever-increasing quality, delivery, and cost performance. They may help by sharing information, technology, and personnel—but not always. In some instances, a small supplier may be more specialized than its larger customer, or may need special training.

Here is where the government resources come into play, in the form of the Kohsetsushi and other public technology centers. The importance of these programs is growing. Many firms want to improve in order to offset reductions in their traditional business lines as their large Japanese customers rationalize or internationalize production. In other cases, large firms are themselves di-

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versifying, compelling their smaller suppliers to shift to new technologies. Meanwhile, stiffer competition from low-cost Asian suppliers, coupled with a tight labor market at home, is intensifying the pressure for small firms to invest in new, labor-saving technologies and upgrade working conditions.

More broadly, the signs are that growing numbers of small Japanese manufacturers want to develop their own products and technologies and then market them themselves both at home and abroad. The proportion engaged exclusively in subcontracting dropped from two-thirds to just over one-half during the 1980s. R&D spending and personnel are on the rise in small firms, as are efforts to improve design capabilities. Small innovative firms are forming geographical clusters in Tokyo and other large cities, and also in such less urbanized locations as the Nagano Prefecture in central Japan. New horizontal and lateral relationships are being developed between and among small firms and in joint ventures with larger firms and with local technology resource centers.

MODERNIZATION POLICIES. All this marks an about-face from Japanese policies after World War II. Then, small firms were often viewed as backward, and policy makers favored building up large corporations, especially in heavy industry and in the field of mass production. Some small firms were combined into bigger ones, and the rest were sheltered from competition.

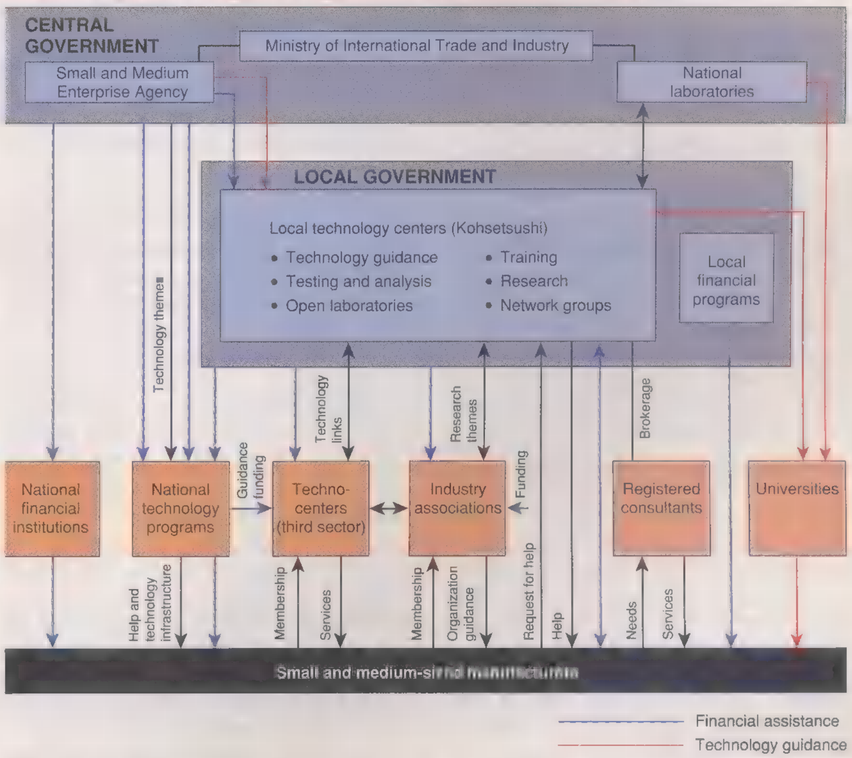
More recently, although some protective measures still exist, fostering inventive, knowledge-intensive small firms has come to be viewed as vital to a national shift toward high technology and more flexible production. Small enterprise promotion and technology improvement are also critical to regional economic development.

Modernization in this context refers not only to strengthening elements internal to a company but also to improving entire sectors of small enterprises, including inter-company and inter-industry relationships. The national laws and policies establish general mechanisms for backing small firms, both individually and in groups, with finance, tax incentives, guidance, and assistance. There are also special measures to help such companies convert to new business lines and develop new products and technologies. The national government assists local programs that support and guide technology development by small firms; funds local technology centers; promotes the clustering of companies for joint product development, marketing, and training; improves design ability in small firms; disseminates information; and stimulates small enterprise research and entrepreneurship.

The principal central agency responsible for small firms in Japan is the Small and Medium Enterprise Agency (SMEA), part of the Ministry of International Trade and Industry (MITI). The agency's functions include overseeing such matters as small company guidance and technology development, subcontracting, enterprise promotion, and planning and research. It can obtain advice and reviews from three national councils for policy-making, stabilization, and modernization.

Other agencies and bureaus contribute, including MITI's Machinery and Information Industries Bureau and the Agency of International Science and Technology, which is attached to MITI. An associated public organization, the Japan Small Business Corporation, guides and finances structural improvement and upgrading projects in small firms; it also trains enterprise personnel and local program staff and makes information accessible at the local level.

Japan's public support systems for smaller firms



Perhaps the most unusual aspect of the multiple means of support in Japan for small and medium-sized manufacturers are the Kohsetsushi. Some 170 of them around the country provide assistance in modernizing a company and developing its technological capabilities.

To complement private financing and promote its modernization policy, the national government has set up three major financial institutions in Tokyo with highly specific goals. The People's Finance Corp. extends funds to very small-scale firms. The Small Business Finance Corp. supplies longer-term funds to small and mid-sized firms. The Shoko Chukin Bank finances small firm cooperatives and small industry organizations.

A recent national policy is to encourage small firms with different specialties to work together on new products. This is implemented by establishing local meeting places, supporting mediators, sharing information, subsidizing business associations and fusion groups, and providing support for production and marketing.

More generally, prefectural and city offices of industry promotion include local development and guidance of small firms. Prefectures and cities also help them invest in plant and equipment through tax relief, interest subsidies on private bank loans, and other allowances. And loans for equipment modernization and systems for leasing equipment are funded jointly by national and prefectural governments.

Nor do business and industrial associations remain aloof. Local chambers of commerce, industry federations, subcontractor promotion associations, and industry-specific structural improvement associations—all receive public financing for their aid in modernizing small industry.

So how much does all this cost? What with the variety of programs and the fact that these initiatives overlap with programs for general business development, regional development, and technology promotion, it is difficult to calculate with any precision how much Japan spends on technology assistance to lesser enterprises. Only a little of the funding is counted in the central government's regular tax budget; most central resources come from trust funds and other capital accounts. The U.S. Congress' Office of Technology Assessment, in Washington, DC, reckons that, all in all, more than $30 billion—or more than 5 percent of Japan's national regular and capital budgets —goes

to support small firms each year, including nonmanufacturers and loans, but excluding prefectural and city contributions and spending on related regional development and technology programs.

KOHSETSUSHI. Kohsetsushi were started at the turn of the 20th century, being modeled in part on the U.S. agricultural experimental stations and extension services. National and university institutes came first, followed in the 1920s and 1930s and again after World War II by local government centers. In recent years, a few new centers have been added, while many older Kohsetsushi have expanded or built new facilities.

Today, there is at least one center in each of Japan's 47 prefectures, with 22 centers in the Tokyo metropolitan region. All told, the 170 centers employ 6900 people, including 5300 engineers and technical personnel.

The Kohsetsushi are administered by prefectural and municipal governments, and are mostly funded by them, to the tune of the equivalent of US $745 million in fiscal 1990. The central government typically provides 10–20 percent of the budget of each center, with funds coming from MITI, the Japan Small Business Corp., and the Japan Bicycle Development Association. (The last-named plows back betting profits from bicycle racing into improving machinery and metalworking industries.) Income from fees for services to private firms is small.

About half of Kohsetsushi staff time is spent on research, mainly on applied projects of relevance to existing or emerging local industries. Projects may be organized by the center itself, or sponsored with local companies or universities. Small manufacturers often send one or two of their staff to work on Kohsetsushi research projects, so that they gain research experience, develop new technical skills, and transfer technology back to their firms.

Jotaro Kishi, chairman of the Hokkai Spring Co. in Hokkaido, has sent his company's engineers to the Hokkaido Industrial Research Institute in Sapporo to learn about new carbon and glass fiber materials and participate in cooperative research projects. With Kohsetsushi assistance, these engineers have already helped the company launch several new products using new materials and innovative cold-weather technologies. The centers also run seminars and study meetings to inform local firms of research findings and new technologies, as well as publish newsletters and research reports and maintain technical libraries.

Conducting tests and examinations is another major Kohsetsushi activity. For nominal fees, a center's laboratories will analyze materials and products, verify standards compliance, calibrate measuring instruments, and make sophisticated testing equipment available. Over 710 000 tests and examinations are conducted yearly to help small firms enhance quality and precision and develop products, as well as resolve problems in materials and components.

A typical client is Hamano Metal Working, a 100-employee manufacturer of heavy truck components in northern Tokyo. When some of its bolts broke, Hamano appealed to the Tokyo Metropolitan Industrial Technology Center. The staff conducted an examination with X-ray and laser equipment and were able to pinpoint what was wrong.

A third part of the Kohsetsushi charter is giving advice and guidance to small companies on how to overcome technical difficulties and implement new technology. For answers to simple requests, company managers call or visit; for more complex problems, center staff make field visits to companies. About 460 000 cases of technical advice are handled annually, including 24 000 in which expert teams and advisors visited firms. There is also a program of technology advisers, in which the centers match company needs and requests with over 4200 registered private manufacturing consultants. The advisers are fully reimbursed from local and central funds for their first round of services to firms.

Training in new technologies for employees of local small manufacturers is provided through group and customized programs by the Kohsetsushi. Employees go to the centers for classroom instruction and hands-on experience with advanced tools, computers, and software systems. Many of the centers offer open laboratories, making their specialized equipment available for research, prototyping, and training. The Kohsetsushi also sponsor technology diffusion and network groups to encourage small firms to exchange information, share technology, and develop new products and markets. Each center may sponsor several such groups, with each involving up to 30 local firms.

REGIONAL PROJECTS. Complementing the long-established Kohsetsushi is the newer, and still growing, regional infrastructure of technology projects, industry resource centers, and technocenters. Outside Japan's booming Tokyo-Nagoya-Osaka core, development was lagging. MITI and other central government ministries therefore established a series of projects to promote the technological upgrading of existing industries and the development of new technologically based enterprises throughout the country.

One of the best-known of these initiatives is the Technopolis program. In the 1980s, it designated 26 areas to serve as nodes for high-technology growth. At many of these sites, newly built technocenters are helping to introduce advanced technologies to local small firms.

Regional technology development is also the aim of the Research Core program. Sponsored by MITI, although funded mainly by local government and the private sector, eight Research Core locations have to date been chosen for special facilities for promoting technology transfer, business incubation, and training among small firms. Other regional technology projects championed by MITI and other ministries include the Key Facilities Concept (promoting facilities for information services and research in peripheral areas) and the New Media Community (developing new information systems in part for local firm networking).

These regional initiatives are themselves complemented by an expanding number of new local industry resource centers, city technocenters, and new training institutes. For example, on the northern island of Hokkaido, the Muroran Technocenter is assisting small manufacturers with training, consulting, marketing, networking, information distribution, R&D, and the use of advanced machines to help diversify the heavy industrial base of the local economy.

Many of the new regional technology projects and industry centers are structured as "third sector" organizations. This usually involves a governing foundation of public and private representatives—a mix that allows more flexibility in activities and staffing, plus access to resources from the private sector.

HOW SUCCESSFUL? The combination of Kohsetsushi, regional and local technology projects, financial incentives, and a supportive national and local policy framework forms an extensive and comprehensive system of support for the modernization of small industrial firms in Japan. Most such firms have ready access to these resources.

Companies report that local centers and other resources are highly valued, particularly because the cost of use is free or nominal. They state that the centers are key in helping them improve old technologies and existing products—probably because the centers, which are not at the leading edge of technology, are not too far ahead of their clients and so can help them resolve day-to-day problems with current technologies.

At the same time, in order to promote more innovation among small firms, many local governments aim to increase the role of local centers in new technologies. This they will do by funding more future-oriented research and by establishing new third sector institutions focused on advanced technologies.

A recurrent issue for almost all local technology centers is personnel. Kohsetsushi staff typically spend their whole career with one center. While this stability encourages long-term relationships with local firms, staff skills can become outdated, and the low turnover limits opportunities to recruit young staff in new areas of technology. The Kohsetsushi are trying to address this question by hosting visiting researchers and increasing education and training for existing staff. In the new third sector technology centers, there is more flexibility in staffing, although even they sometimes find it hard to attract good researchers and technical staff.

The United States, in contrast, has a

Japanese and U.S. use of new manufacturing technology

Equivalent types of new manufacturing technology		Japanese enterprises			U.S. establishments			Japan/U.S. ratio[b]	
Japan	United States	Small, % (a)	Large, % (b)	Ratio (a/b)	Small, % (c)	Large, % (d)	Ratio (c/d)	Small (a/c)	Large (b/d)
NC/CNC machine tools	NC/CNC systems	57.4	79.4	1.4	39.6	69.8	1.8	1.4	1.1
Machining centers	FMS cells or systems	39.4	67.4	1.7	9.1	35.9	3.9	4.3	1.9
CAD	CAD/CAE	39.1	75.2	1.9	36.3	82.6	2.3	1.1	0.9
Automatic transport vehicles	—	34.9	68.3	2.0	—	—	—	—	—
—	Automated guided vehicles	—	—	—	0.8	13.1	16.4	—	—
Automatic inspection/ measuring	Automatic inspection, final product	30.1	66.7	2.2	10.5	44.3	4.2	2.9	1.5
Automatic warehouse equipment	Automatic storage and retrieval	22.6	62.2	2.8	5.5	43.3	7.9	4.1	1.4
Handling robots	Pick-and-place robots	10.9	44.9	4.1	1.9	24.4	12.8	5.7	1.8
Assembly robots	Other robots	8.3	41.4	5.0	3.9	35.0	9.0	2.1	1.2
Welding/painting robots	—	16.0	42.7	2.7	—	—	—	—	—

Source: Current Survey on the Manufacturing Industries, 1988, reported in *Small Business in Japan, 1988* (Tokyo, 1989), a 1989 White Paper from the Ministry of International Trade and Industry's Small and Medium Enterprise Agency; *Manufacturing Technology 1988* (Washington, DC, 1989), Current Industrial Reports SMT(88)–1, from the Bureau of the Census, U.S. Department of Commerce

a The two categories, small and large, refer to Japanese enterprises employing, respectively, under 300 and 300 plus and to U.S. establishments employing, respectively, 50–499 and 500 plus.

b Comparisons are approximate because of differences in the definitions of technology and organization and in employment size categories.

CAD/CAE = computer-aided design/engineering; FMS = flexible manufacturing system; NC/CNC = numerically controlled/computerized NC.

much more limited public infrastructure to help firms overcome problems and modernize their operations. There are several well-run state- and Federally supported industrial extension and technology deployment programs [see story, below]. But these are exceptions; U.S. efforts are not nearly on the same scale as Japan's, whether in basic services, long-term stability and public financial support, or national commitment to industrial modernization.

Japan's approach may not be appropriate in other industrialized countries where conditions are different. But it does teach the fundamental lesson that policies and programs for industrial modernization need to be comprehensive if they are to foster thoroughgoing technological improvement among most small manufacturers.

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Extension programs help small U.S. firms

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The U.S. government, spurred by the continuing recession and increasing frustration over the loss of the country's manufacturing base to foreign competition, has in the past year earmarked some US $350 million for programs intended to improve manufacturing. (This includes funding provided by the Advanced Research Projects Agency for defense conversion efforts and by the Competitive Technology Act, which has yet to be passed by the Senate.) State governments have also launched manufacturing assistance programs, spending at least $100 million last year (including $20 million from Federal sources).

These dollars went, for example, to solve a manufacturing problem that made electronic funds-transfer cards unreadable, to provide access to a wind tunnel for analysis of wire to be used for overhead transmission lines, to assist in evaluating a computer-based reading aid intended for learning-disabled students, as well as to help tens of thousands of companies nationwide solve their individual technical problems.

Unlike past efforts, these funds have generally been targeted at small and mid-sized manufacturing enterprises with less than 500 employees. Such companies—some 355 000 of them employ 8 million workers—make up 95 percent of the U.S. manufacturing base. They face the most acute modernization problems. Most are not using the latest manufacturing technologies because they lack the expertise, money, and time needed to improve their current operations while bringing in new technologies and methods.

A number of programs have been established to address these needs. Perhaps the most successful so far are the manufacturing extension programs. Modeled after the hugely successful, though expensive, agricultural extension programs introduced 50 years ago, these programs make available to small manufacturing enterprises the resources of academia, the national laboratories, and, where appropriate, private companies. The assistance is rendered through some type of university-industry partnership, and often with the close collaboration of state agencies. At the beginning of 1993, 23 state governments and more than 100 universities had established technology transfer, industrial extension, and business assistance programs.

STATE PROGRAMS. State assistance for manufacturing has a long history. Manufacturing extension programs first appeared when North Carolina and Georgia, in 1955 and 1960, respectively, opened regional offices staffed by professional engineers to help attract new industries and aid local firms in solving their technical problems. The programs spread in the late 1970s and the 1980s, especially in the Northeast and Midwest. Today, there are 25 to 30 state programs whose primary function is to assist small and medium-sized businesses, more particularly manufacturers, to adopt new technologies.

Technical assistance spending varies widely among the states, as shown in the figure on p. 75. Not shown here is the fact that the amount spent is not proportional to the number of manufacturers in any given state.

Programs are of three types: active programs, which include services from technical needs assessment to consultation assistance; broker programs, which provide limited direct assistance but put industrial clients in touch with people who can help; and passive programs, which provide information only.

Active programs include university-based field office programs, which employ full-time engineers to work with manufacturers. The Georgia Institute of Technology, Atlanta, administers the largest program of this type, with a network of 12 regional

offices and 26 field staff members. Engineers provide two to five days of assistance at no cost and also serve as conduits to other Georgia Tech programs for productivity and management improvement.

These other programs include the Georgia Productivity Center, which provides up to 15 days of assistance to firms trying to improve productivity and technology, as well as the Federally funded Trade Assistance Center, which provides 60 to 80 days of intensive assistance to qualified, trade-affected firms. Georgia's budget for these programs is about $2.5 million per year; last year the program responded to 960 requests for help.

GEC Automation Projects, Macon, GA, was one beneficiary of Georgia Tech's assistance. The company produced a motor control that would fail after one of its onboard microprocessors appeared to "fall asleep." Engineers at the company thought electromagnetic interference (EMI) might be the problem, but did not have the tools or expertise to find out. The Macon regional office sent an EMI specialist to the plant, logic analyzer in hand. He confirmed that interference was indeed causing the failures, and helped the company redesign the motor control.

Active state programs also include technology centers and consulting services, which emphasize not only problem-solving but also technological modernization. These programs provide companies with thorough technology assessments and implementation assistance, including training. Although they may be linked with universities, they are not directly part of a state's university system, and frequently employ private consultants. Some programs charge a fee for their help.

One such program, the Michigan Modernization Service at the Industrial Technology Institute, a private, nonprofit organization in Ann Arbor, was dedicated to the development of state-of-the-art manufacturing technologies. It provided free consultations to small and mid-sized Michigan manufacturers in technology deployment, workforce development, and market analysis. The program served between 120 and 140 firms in 1988, with a budget of $2.8 million. But state budget cuts eliminated the program, just before Federal funding was awarded. The Federal money will instead be used to establish the Midwest Manufacturing Technology Center on the foundation of the modernization service

REFERRAL SERVICE. State programs that act as technology brokers serve primarily to disseminate information about new technologies to manufacturers. An example is the Pennsylvania Technical Assistance Program, based at Pennsylvania State University, University Park, which employs eight technical and engineering specialists to field requests for information and make referrals to faculty members, Federal and private laboratories, computerized databases, and library resources. This

European policies support small firms

Government in Europe regards small and medium-sized manufacturers as a vital part of the economy. In fact, some of the most innovative programs for technology-based assistance to such firms are found in Denmark and parts of Italy and Germany. Each has developed a manufacturing version of the highly successful U.S. agricultural extension service.

DENMARK. Closest to the U.S. model is Denmark, with its 15 local Technology Information Centers. The program was launched in 1971 and is funded jointly by the country's National Agency of Technology and local governments. It is managed by the Danish Technological Institute in Taastrup. The centers answer technical questions and also act as brokers between their clients and sources of technical assistance.

Each office has three to six full-time industrial experts on its staff. In 1987, the staffs visited 6300 firms, mostly at their request, and made 2900 referrals, 40 percent of which were for help with product or process development.

The country also has several autonomous academies of technology and science, each of which develops a targeted technology. The Danish Technological Institute conducts multidisciplinary R&D. All these organizations work in cooperation with industry.

In the north of Jutland, the European Commission established a five-year program in 1986 to spur technology-related development. Each town was invited to design a program and enter it in a competition. Perhaps the best was TekNord, a program for sharing technology managers. In the small town of Sindal, seven experienced manufacturing managers each contracted with five to eight firms to be on their staff for at least 2 1/2 years. They would take on technology application projects for which the staff lacked time and serve as "sparring partners" for the owners or managers. Every six months, the share of their salary paid by the companies increased.

Today, though the grant from the European Commission has expired, the program is flourishing. Ten managers are each fully contracted out to Danish manufacturers that are in the process of choosing new technologies.

ITALY. In the Emilia-Romagna region, local offices of trade associations and sector-based service centers undertake many of the functions of U.S. industrial extension services. The most active trade association is the National Confederation of Artisans, which has offices in more than 250 towns and villages throughout the region. It supplies accounting services, including payroll and taxes; maintains information bases; provides technical education; and helps firms evaluate investment decisions and raise capital.

Then there are the numerous service centers started by the Regional Board of Land Economic Development (known as Ervet in Italian). They help the firms with applied research, quality assurance and testing, and market and technology scanning. Though important in the emergence of the region as an industrial power, the centers have suffered from recent national budget cuts, and many have had to reorganize. The region can also turn to the offices located throughout Italy of the institutes of the National Research Council and the National Commission for the R&D of Nuclear and Alternative Energy Sources.

GERMANY. In the Baden-Württemberg region, the Steinbeis Foundation, set up in 1984 by the regional government as a private, nonprofit corporation, runs more than 120 technology-transfer centers. These are housed in universities and polytechnics and directed by professors employed by the foundation to solve technical problems, do R&D, and provide market information. In 1991, for example, the foundation had 15 744 projects in hand.

In a complementary program, the Fraunhöfer Society for the Promotion of Applied Research has 13 (of 36) institutes in the region. These institutes are funded by industrial clients.

IN GENERAL. The European programs charge fees for many of their services, though the introductory evaluation of the company's problems is free. They aim at being self-supporting, but this works only some of the time.

The European programs also emphasize cooperation between companies. Firms form industrial networks to compete with larger companies, to gain access to technologies or market information they could never afford on their own, or to learn from each other.

To illustrate, in Emilia-Romagna, networks have been part of the business culture for years, and many government programs stimulate such cooperation by giving preference to applications from groups of firms. Small and mid-sized German firms also collaborate in several areas, including loan guarantee cooperatives, training, quality management, and R&D. Denmark, looking for an entree to the new European market for its very small firms, became the first European nation to create a special program to stimulate networks in a different culture. Such networks had occurred naturally in Italy.

Beyond purely regional efforts, the European Community has attempted in many of its programs to meet the needs of small and medium-sized manufacturers. For example, the programs for Basic Research in Industrial Technology for Europe (Brite), for R&D in information technologies (Esprit), and Eureka, the 19-nation collaborative R&D program, emphasize this area in their organizational principles. —*Stuart A. Rosenfeld*

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program, established in 1965, receives about $900 000 annually and responds to requests from about 850 private firms and 450 other organizations.

A MAJOR PLAYER. In the last few years, the National Institute of Standards and Technology (NIST) has become a major player on the manufacturing extension scene. NIST funds seven Manufacturing Technology Centers around the United States (the new Michigan program is one), and has granted 23 states funds to assist them in planning extension programs. This year, NIST will provide $87 million in contracts for Manufacturing Extension Programs to assist small manufacturers in upgrading their capabilities to serve both commercial and defense needs, building on programs sponsored by regional, state, or local governments and nonprofit organizations.

NIST will also provide $182 million in other assistance, for such things as dual-use technology programs, and another $50 million for manufacturing education and training. (To put these numbers in perspective, in 1990, public spending in the United States on agricultural extension activities was $1.1 billion. Japan spends $500 million a year on its system of technology assistance for small and medium-size manufacturers [see "Japan looks after the little guys", p.70]. By comparison, including all plans proposed by the Competitive Technology Act now being considered by Congress and by the Department of Defense, total annual U.S. government funding will amount to only $350 million.

The NIST programs, though a step in the right direction, have received criticism regarding their effectiveness and their links between the customer and the service providers. Private-sector–driven programs may be closer to the needs of the customer, say the programs' critics.

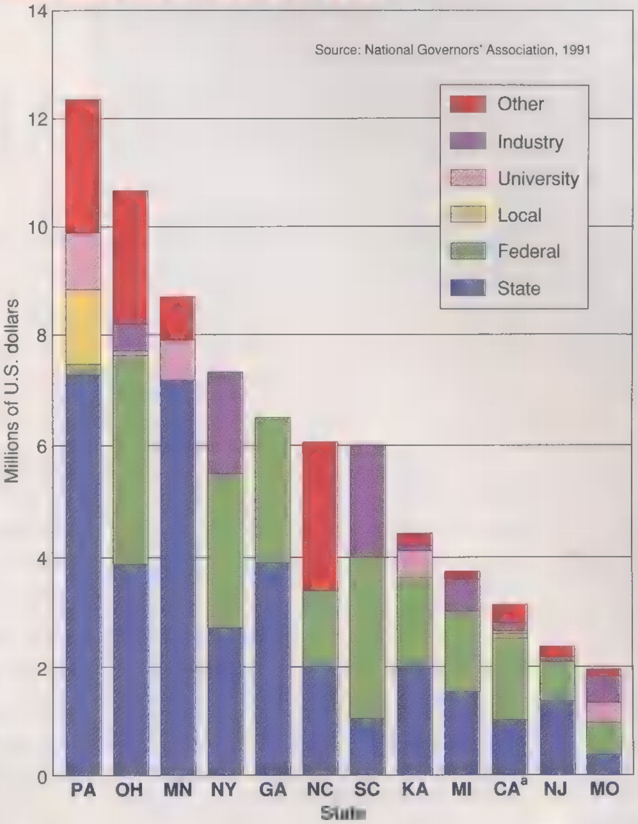
EVENTS IN CALIFORNIA. With NIST funding, California in 1992 formed a Manufacturing Excellence Council, under the state Department of Commerce, to coordinate assistance methods. Service providers include private companies and consultants, two state university systems, a large network of community colleges, national laboratories, and many private universities and colleges. Programs are varied.

At El Camino College in Los Angeles, for example, the new NIST California Manufacturing Technology Center is chartered to help with technology transfer to small and medium-sized manufacturers, to keep aerospace suppliers competitive, and to assist companies in making transitions from defense to commercial applications. At California State University, Chico, the Center for Manufacturing Excellence helps local businesses implement new technology. At California State University at Long Beach, the Engineering Problem Solving Initiative and the Continuing Engineering Education program provide seminars for engineers working in local government and industry.

Meanwhile, the University of California has just started a new Manufacturing Extension Program modeled after its agricultural extension program. It aims to bring university research and academic expertise to bear on business problems in regulatory compliance, employee training and retraining, technology, management techniques, and other areas. Its goal is to establish and maintain a statewide network of advisors. A pilot program with four advisors at four University of California campuses in the southern part of the state was launched this April. A fully funded statewide effort, with 100 agents, could provide services to 5000 manufacturers annually, 10 percent of the state's total.

These programs are not without pitfalls. The number of manufacturers reached usually represents only a small percentage—usually less than 10 percent—of the small and medium-sized firms operating in a state. Some programs have failed due to lack of state support, lack of qualified staff, or inability to contact the companies needing help the most. Nonetheless, understanding as to what makes a successful program is beginning to emerge.

The 12 states with the most spending on technical assistance in 1991[a]



[a]California figures are for 1993.

STEPS TO SUCCESS. As was the case with agricultural extension programs, providing field service is critical. Helping small firms upgrade manufacturing systems and introduce new technology is usually not a straightforward process: it requires considerable tailoring to the needs, capabilities, and resources of each client firm. The ability of the service's professional staff to make house calls—to make detailed assessments and develop in-depth working relationships—makes a real difference when it comes to stimulating technological upgrading.

Bringing in new machinery is not enough. Sometimes the most crucial steps toward improved manufacturing productivity involve enhancing the skills of employees and rethinking workplace operating systems. In addition, technologies need to be approached pragmatically. While the latest computer-integrated manufacturing systems and sophisticated assembly lines may be suited to large manufacturers, smaller companies are likely to be better served by adopting established, readily available technologies that can be easily operated and maintained.

In the long term, these efforts must extend beyond assisting individual manufacturers and reach out to developing and strengthening industrial and regional systems. Public commitment is vital. These industrial assistance programs are certainly not quick fixes.

Rather, the programs must take the long view when working to improve productivity and quality, technical capability and flexibility, and management and labor skills. Programs therefore need stable support so that the people that carry them out can maintain the confidence of the business community, form lasting relationships with the companies they serve, and attract and retain first-rate technical staff.

While the current efforts to assist U.S. manufacturers are notable, a question remains: How likely are they to last, or are they just a flash in the pan? When the recession begins to diminish and defense workers begin to find new careers, what will happen to the focus on manufacturing? These efforts, critical as they are to the international competitiveness of the country, may evaporate.

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Training for manufacturing

The study of manufacturing engineering at the university level was a required element in many engineering programs before World War II, but faded from the academic scene as schools became more focused on math and science. Recently, educators worldwide have begun to reemphasize the importance of manufacturing processes, materials, controls, and the like, with Germany's programs in manufacturing standing out as the most rigorous so far. University-level manufacturing education programs differ worldwide, and new programs are continually being established. Meanwhile, some educators are concerned that after graduation from high school may be too late to introduce students to technology and to the skills needed in today's workplace, and various programs for middle and high school students are being launched.

Master's programs and more

Kornell F. Ehmann and Philip C. Jones
Northwestern University

Efforts to turn around a Bell & Howell unit, whose market share has suffered from intensified competition and whose manufacturing processes and systems urgently require restructuring, are the responsibility of Fred Hagedorn.

A group of engineers at S&C Electric Co., who work at the interface of design and manufacturing both to help cut the time required to develop new products and to ensure that products and manufacturing systems work together as intended, is headed up by Dave Ritland.

A third group, this one charged with improving the processes for developing new products at MacNeil Consumer Products, is led by Matilda Ko.

Hagedorn, Ritland, and Ko are recent graduates of Northwestern University, in Evanston, IL. They belong to a growing elite in the United States who have studied manufacturing in both engineering and management terms. That combination was offered at no U. S. university until recently, when numerous initiatives in manufacturing education began springing up. Ranging from newly developed undergraduate programs to a Ph.D. program, they suggest no single direction, save that U.S. education in manufacturing is fast becoming interdisciplinary.

Within Europe and Japan, in contrast, higher education in manufacturing has a long tradition, with well-established programs at most major universities.

After World War II, the U.S. manufacturing industry had a huge competitive advantage over its counterparts in Europe and Asia, in part because most of their industrial facilities and infrastructure had been devastated. In such industries as consumer electronics, automobiles, and machine tools, U.S. companies were dominant for decades, and the country grew complacent, believing that it had solved the problems of production.

SCIENCE AND MATH FIRST. This view of the world molded engineering and business education. In engineering, science came first, followed by mathematics. Lab courses in which the use of machine tools taught students about manufacturing processes were thrown out, as were many design courses. Business education emphasized marketing, accounting, finance, and, often, operations, which covered such subjects as scheduling and inventory control, but not process design or materials, each in isolation. And graduates of these programs went on to create organizations with isolated functional areas, in which it was difficult to translate the results of research into commercially viable products and processes.

But during the Cold War, other countries prospered. The United States lost its consumer electronics industry, and its market shares in automobiles and machine tools have declined. But the educational system has been slow to respond. As late as 1984, the Accreditation Board for Engineering and Technology (ABET), the U.S. board for approving college programs in engineering, listed only two accredited programs leading to a bachelor's degree in manufacturing engineering in the country, and one was merely an option in the mechanical engineering department.

More recently, U.S. companies have awakened to the need to change in order to compete worldwide. Academia, though trailing industry, has begun to realize that business and engineering educational programs must change as well.

In fact, interest in educational programs for manufacturing has rebounded across the country, as a number of U.S. universities have implemented or are in the process of creating innovative programs.

Manufacturing programs are better established at universities in Japan and Europe. The upper division curricula in European programs are outstanding, having greater depth as well as more formal cross-linkages with industry than the U.S. or Japanese programs do.

OUT EAST. Undergraduate engineering programs in Japan follow the U.S. model. In a four-year bachelor's program, the first two years consist of coursework in languages, humanities, social sciences, physics, chemistry, and mathematics and the final two years are devoted to an area of specialization. The programs at Osaka University and the University of Tokyo are examples [see upper table, opposite page]. There are some differences, however: Tokyo University sets great store by design and computer information systems, whereas Osaka emphasizes materials. The programs at each school stress processes.

They also stress laboratories. In both programs, students spend at least two afternoons a week in a lab. The laboratories at Tokyo University in particular emphasize hands-on experimentation and practical exercises involving drafting, machine tools, and metrological instrumentation. The Osaka laboratories appear more theoretically based. This difference is not surprising, given the relative weights of design and materials in the two curricula.

Neither institution seems to interact much with industry. They do not require student industrial internships or cooperative education programs in which students alternate between going to school and working at a sponsoring company. Nor is there much industrial involvement in faculty or graduate student research. This situation is common at Japanese universities, which may seem surprising in light of the generous financial support some Japanese corporations have given to U.S. universities.

IN EUROPE. Because each country on this continent has a different secondary education system, based on its culture and educational philosophy, the university programs vary. In the lower division curricula (the first two years of a traditional four-year university program), the differences are minor. For instance, the University of Manchester's Institute of Science and Technology in England is able to confine the lower division coursework to the first year because of its students' solid preparation in secondary

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school (comparable to U.S. high school).

Most European programs lack mandatory courses in the humanities and social science, probably because the European secondary schools cover these areas well.

In the upper division, differences are more pronounced. Typically, European manufacturing programs are closely coupled with mechanical engineering programs. Even when crossing disciplinary boundaries, the curriculum gives pride of place to traditional mechanical engineering disciplines related to the manufacture of discrete goods. They all place considerable emphasis on basic manufacturing processes and technology, followed by design and controls. Materials get less attention than in Japan, in part because they are covered in the lower division curricula. Laboratory work is compulsory in nearly all lower and upper division science and engineering courses.

In addition, most programs require actual industrial experience. Students at the Manchester Institute must perform industrial internships during their eight-week summer vacations. The Technische Universität at Berlin, Germany, which offers a five-year program, requires a 26-week-long industrial practicum. In the first 13 weeks students work with such basic processes as forming, cutting, assembly, and metrology; in the last, they work in more specialized areas such as electronics manufacturing. In this regard, the German system is the most rigorous in the world, but it can be because it relies on the systematic countrywide apprenticeship program supported by all segments of the country's industry.

All the programs demand a lot of independent project work, usually linked to industrial participation. Both the Katholieke Universiteit Leuven in Belgium, also a five-year program, and the Technische Universität in Berlin call for a thesis during the fifth year of the program.

Some manufacturing engineering curricula*

No. of semesters in:	Processes	Design	Management/ industrial engineering	Materials	Computer/ information systems	Controls
United States						
Northwestern University Chicago						
Traditional program	2	2	0	3	1	2
New program	3	4	3	2	1	2
University of Wisconsin-Madison	2	3	1	1	1	1
University of Michigan, Ann Arbor	2	2	0	1	1	1
Europe						
Katholieke Universiteit Leuven, Belgium	5	2	2	0	1	4
Technische Universität Berlin, Germany	8	3	2	0	0	2
Universiteit Trondheim, Norway	6	2	3	1	1	3
University of Manchester Institute of Science and Technology, UK	5	3	9	0	2	0
Japan						
Osaka University†	(14)	(2)	(5)	(10)	(1)	(2)
University of Tokyo	10	6	3	3	3	2

* For upper division undergraduates only (juniors and seniors in the United States).
† Here the unit is a quarter course.

Formal university-level training leading to a degree in manufacturing is a recent phenomenon in the United States. Only a handful of bachelor's programs in manufacturing engineering exists and few are being developed; mostly the subject is handled within traditional mechanical or industrial engineering departments. But graduate-level education in the area is booming, with several degree programs recently developed and more in the wings.

When manufacturing is an option for students studying mechanical engineering [see table below], the selection of courses is typically rather limited. While they usually provide a good introduction to the mechanical aspects of manufacturing, they place far less importance on processes than do the undergraduate programs in Europe or Japan. For that reason, a separate manufacturing engineering program recently established at Northwestern offers additional work in processes and design. The program also mandates participation in co-operative education.

In general, U.S. undergraduate programs in manufacturing devote the first two years to basic science and engineering; programs in Europe and Japan at this level introduce students to manufacturing and design. U.S. programs rely comparatively little on state-

Collaborative manufacturing and business graduate programs

University	Degree	Core	Manufacturing track	Electives
Massachusetts Institute of Technology, Cambridge	Leaders for Manufacturing Program (master's)	System optimization, probability and statistics, accounting, markets and business strategy, strategic management, communication for managers	Total quality management, operations management, seminar in manufacturing, introduction to marketing, research project in manufacturing, organizational leadership and change, manufacturing policy, manufacturing track elective (finance, human resource management, or information technology)	Varies by engineering department but generally at least four additional courses must be taken, including one in design and development as well as one in processes or materials
Northwestern University, Evanston, IL	Management in Manufacturing (master's)	Quantitative methods, management of organizations, accounting, organizational behavior, finance, marketing, economics of the firm	Total quality management, materials management, factory physics, seminar in manufacturing, manufacturing human resource management, product and process management 1& 2, manufacturing strategy, manufacturing practice elective (manufacturing practice, project management practice, and so on)	Nine electives chosen from any school or department at Northwestern University
Stanford University, California	Future Professors Program (Ph.D.)	Required courses of home Ph. D. department (engineering or business)	Manufacturing seminar, manufacturing systems analysis, understanding manufacturing processes, manufacturing organization, design for manufacturability, manufacturing performance measurement, manufacturing information and coordination	Electives as required by home departments

Students in Northwestern University's Masters of Management in Manufacturing program receive ample hands-on experience in Northwestern's manufacturing laboratories. The program is a joint venture between the Kellogg Graduate School of Management and the McCormick School of Engineering, and graduates receive one degree, awarded jointly by the two schools.

of-the-art laboratories or a systematic sequence of independent experimental work.

Most laboratory facilities in U.S. academic institutions are woefully incomplete. Most have elected to concentrate on only a small number of processes. A few have developed computer-controlled assembly cells; some have small machines to illustrate such concepts as NC programming. One thing lacking is the ability to give students good hands-on experience with a wide variety of processes. Also lacking is the integration of these laboratories into other coursework to help students develop an intuition on how to solve problems in product development and on the factory floor. U.S. programs also give short shrift to the interrelation of design and manufacturing, and to manufacturing processes. Interaction with industry is slight, unlike in Europe. And "nesting" manufacturing within a traditional engineering department tends to provide an overly narrow education.

MASTER'S PROGRAMS. At the graduate level, U.S. manufacturing education really began in 1984, when IBM Corp. awarded several U.S. educational institutions grants to set up master's programs. North Carolina State University at Raleigh established an MS in manufacturing, which is run as an interdisciplinary program under the N.C. State Integrated Manufacturing Systems Engineering Institute. Various departments such as industrial, mechanical, and electrical engineering take part.

Additionally, Stanford University in California and the University of Wisconsin, Madison, both used IBM grants to establish training in manufacturing systems. The Stanford program, a collaborative effort between the departments of mechanical and industrial engineering, takes one academic year. Since its inception, 260 students have been graduated from this program. In 1990, Stanford expanded the program to offer a dual degree option with the School of Business; this program takes two years plus one quarter to complete.

At Wisconsin, the Manufacturing Systems Engineering program has graduated over 140 students. And Purdue University, in West Lafayette, IN, long recognized for its research in manufacturing, both researches and teaches manufacturing within a traditional engineering department structure.

In 1988, the first collaborative graduate program to join an engineering and a business school enrolled its first students at the Massachusetts Institute of Technology (MIT), Cambridge. In the Leaders for Manufacturing program, a two-year, dual degree program, students must do the coursework needed to earn both an MS in a traditional engineering discipline and an MS in management from MIT's Sloan School of Business. All students in the program receive financial aid. Formal course requirements are divided into a core, which includes managerial perspectives; a manufacturing track requirement; and an engi-

High schools take the wrong road

U.S. culture is more interconnected and dependent on technology than ever before. The knowledge and skills it demands from its workers are a world away from those taught in U.S. schools, which until recently saw their primary mission as preparing students for higher education. But even entry-level employment today requires a technological proficiency greater than that required by higher education.

The workplace has changed. Today's employers are asking workers to do more. Decision-making has filtered down through the ranks. Workers now have to manage their work stations, schedule their time, think about quality, solve problems, and apply their skills to new technologies.

Manufacturing, too, has changed. Factory employees no longer necessarily perform routine, repetitive tasks. Because of the use of flexible automated manufacturing systems and electronically controlled (rather than mechanical) equipment, they must process information symbolically. Instead of manipulating parts of a machine, for example, workers must now interact with symbols on a computer. Higher-order language and reasoning skills are often required. Because companies reset their assembly lines many times a day, assembly-line workers must deal with quality control. They must use statistical numerical controls and understand other advanced technological applications involving statistics, logic, probability, measurement systems, and applied physics. They must be familiar with wide-area network systems and do a great deal of technical reading and writing.

Schools today do little to address these responsibilities. Indeed, at the very time that this transformation in manufacturing was taking place, many U.S. high schools were adding traditional math, science, and language arts courses to the curriculum, instead of such needed subjects as statistics and measurement systems. In fact, the skills and knowledge of today's high school graduates are practically identical to those of graduates in the 1950s, making these students unemployable in the manufacturing sector of the 1990s.

Like production and manufacturing, the service sector also is starting to move toward automation. Automatic teller machines (ATMs), for example, have changed the way the banking industry is staffed. In the last five years, ATMs have replaced 40 percent of the cashiers and tellers across the nation and may replace an additional 40 percent in the next five. The fastest-growing group of jobs in the banking industry involves setting up, operating, and maintaining ATMs and related information systems. Most banks cannot easily retrain their cashiers and tellers to work with the ATMs, because the positions do not require the right math, science, and language arts skills. As a consequence, banks have begun to contract these jobs out to companies based overseas and to lay off cashiers and tellers.

neering option [Table, p. 77]. Furthermore, all students must engage in a series of leadership and integrative activities throughout both years, and must undertake a formal six-month industry internship. The coursework culminates in a thesis analyzing the internship experience.

In 1990, Northwestern launched the Masters of Management in Manufacturing program. This is a joint venture between the Kellogg Graduate School of Management, Evanston, IL, and the McCormick School of Engineering. As at MIT, the Northwestern program requires two full academic years; unlike MIT, Northwestern graduates receive only one degree, awarded jointly by both schools. Both the Northwestern and MIT programs have significant industrial input.

The Northwestern coursework has two cores—in management and in manufacturing courses—and various electives. Some courses are taught by teams of members of the McCormick and Kellogg faculty as well as industrial experts. Many demand a heavy load of lab work. Students take part in a three-month summer internship as well as in a series of leadership and team-building exercises on the theme of continuous improvement.

No thesis is asked for. Instead, in their second year, students submit to a capstone course in product and process management, which teaches how to develop a new product hands-on. Student teams each undertake a project in which they must identify a market need, design and prototype a product, plan a manufacturing process, and develop a comprehensive marketing plan.

The newest and most unusual collaborative program in the United States, at Stanford University, enrolled its first students in the 1992–93 academic year. Entitled the Future Professors Program, it aims to train future manufacturing faculty and it grants a Ph.D.

Students apply first to traditional engineering or business Ph.D. programs (and must meet those course requirements), then to the new program. They supplement their usual studies with six special courses in manufacturing: manufacturing systems analysis, understanding manufacturing processes, manufacturing organization, design for manufacturability, manufacturing performance measurement, and manufacturing information and coordination. Other professional development includes seminars and field trips. Students receive generous financial aid, and graduates accepting faculty professorships in the United States will take with them handsome start-up funds for research. The program enrolls five students per year.

More collaborative programs are in the works. The University of Wisconsin has announced a master's program that will be a joint effort between the engineering and the business schools. Other institutions, while looking at joint programs, fear that institutional barriers will make cooperative programs difficult to implement. It is to be hoped, though, that with these programs as a model, barriers to cooperation between engineering and business schools are beginning to crumble.

In sum, in the leading industrial countries, undergraduate programs for manufacturing education are converging on three essential components: solid fundamental knowledge, hands-on experience through laboratory or industrial involvement, and an independent project. Today the European programs, above all in Germany, seem the closest to this objective. Japan is actively changing its traditional programs. And the United States is moving swiftly to close the gap opened by neglect of manufacturing education through the past three decades.

At the graduate level, the United States has been experimenting with the most unorthodox approaches of the three industri-

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The job of technician has undergone similar changes. Auto mechanics are one example. In the early 1980s, when most cars were still mechanically based, mechanics used their senses to diagnose a car's problem--listening, touching, watching--and relied on their mechanical aptitude to fix the car. Most present-day cars are computer based, however, with microprocessors and electronic circuit configurations that are impossible to troubleshoot by sight or sound. The technician must use diagnostic equipment and computerized technical manuals. If the problem is other than routine, the technician must write a technical statement to describe what is wrong with the car. The statement is entered into a wide-area-network computer system, which searches a database and prints out technical instructions on how to fix the car. U.S. high schools today do not teach the skills needed to work in a manufacturing job, or for a bank, or as an auto mechanic.

To better prepare the students for the workplace and society, the country must have the courage to abandon its traditional curricula and graduation criteria and embrace a new educational model, one that some educators call "tech prep." Tech prep generally begins in middle school or high school with a rigorous program in applied academics, with mathematics, science, and language arts being taught in terms of their practical applications. Technical reading and writing, applied physics, statistics, logic, probability, and measurement systems are basic technological skills, but the curriculum must also include human relations, information systems, and organizational and personal skills. These subjects, which lay the foundation for both employment and lifelong learning, should be part of all students' education.

In the second part of the comprehensive tech prep program, students not planning to attend a four-year university may build on their applied academic skills by choosing an area of specialization, typically in grades 11–14, to prepare them for their first jobs. Those who go on to a community college (grades 13 and 14) or technical school will add to their skills and qualify for a wider range of jobs. For example, a student with skills in computer graphics could earn an associate degree in computer design and manufacturing, while another who specialized in agricultural production in high school could obtain an associate degree in production and management.

For any technical preparation program to be effective, there must be careful coordination between the curricula of the secondary and the post-secondary school, whether the latter is a community college, a technical college, or a four-year institution. Planning and cooperation between academic and vocational teachers are essential.

The national version of the tech prep initiative was created by the Perkins Act, the school reform legislation reauthorized by Congress in 1991, and grew out of the program's success in states such as North Carolina and Oklahoma. Thanks to nearly US $1 billion in Federal funds, the program is now being applied nationwide. Other reform initiatives are likewise attempting to integrate the curriculum, identify and teach the skills students will need, and emphasize the application of basic knowledge.

In contrast to these programs, the school reform movement of the 1980s raised academic standards but failed to make the changes that would prepare students for the new work world.

One of the primary concerns at this time was the need for basic literacy for high school graduates and adults. We attempted to attain this goal by recreating the schools of our youth--increasing academic requirements and, for students unable to function well academically, creating alternative programs combining literacy and traditional vocational skills.

The assumption was that the traditional but more rigorously taught curriculum would rectify the problem. But today's technology requires different skills. As a result, despite 10 years of school reform, there now exists the greatest gap in U.S. history between what high school graduates can do and what they will need to do. The reformation of the curriculum and graduation criteria are vital to this nation's survival.

—Willard R. Daggett

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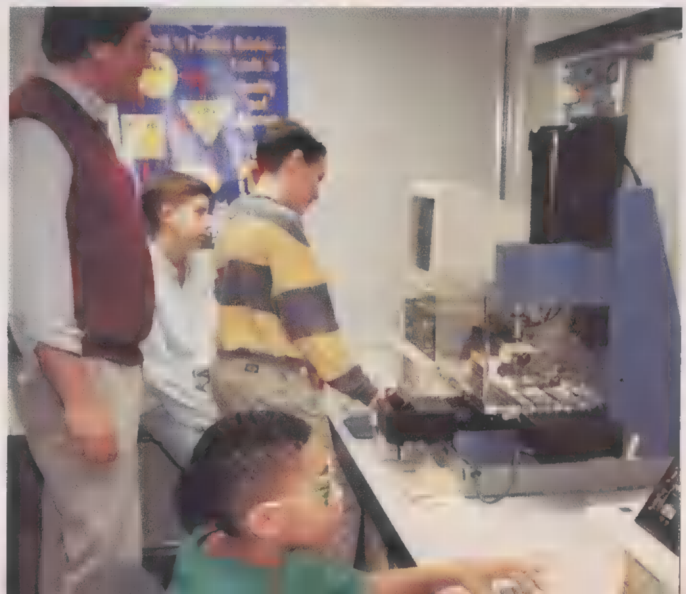
Planned for nationwide implementation, the Manufacturing Technologies Laboratory (MTL) moves from school to school, taking state-of-the-art technology to middle-school students and their teachers.

An engineering workstation running solids modeling software in the MTL's Materials Removal Lab displays the four typical views of solid object design.

Lee Patch [above right], a technician at the National Center for Manufacturing Sciences, reviews the surface-mount technology featured in the MTL Electronics Lab with NASA Administrator Daniel S. Goldin.

Students in the MTL Materials Removal Laboratory use CAD/CAM to create a product of their own design with the same computerized numerically controlled equipment that is used in actual manufacturing.



alized regions. The hope is that a fusion of business and engineering education will equip students to work with the sophisticated manufacturing systems of the next century.

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Hitting the road with manufacturing know-how

Robert F. Johnson   Digital Equipment Corp.

You are a teacher in a classroom full of lethargic ninth-graders eager for summer break to begin. You glance out the window and say, "Here comes the Electronics Lab," and they all rush to your desk demanding their turn. You say, "Yes, you'll all have a turn at learning—hands-on—how to wire a board. We'll also learn about careers in electronics in case you decide to go into this field when you graduate from high school or college."

The inadequacy of today's education system at guiding enough middle and high school students into engineering is notorious. Students are turned off by theory without application, by outmoded educational methods, and by some teachers' ignorance of today's working environment.

Upon graduation, these students are ill-prepared for jobs requiring high levels of technical skill plus an ability to work in teams and a facility for solving problems. As a result, industry spent US $210 billion on education and retraining in 1991, according to the newsletter *Focus*, to bring the workforce in the United States up to the necessary level of competency.

TRAVELING LABS. Beginning in 1986, several concerned U.S. manufacturers, which by now include Digital Equipment Corp., AT&T, Ford Motor, General Motors, United Technologies, and Texas Instruments, formed the National Center for Manufacturing Sciences (NCMS) consortium, a public and private partnership whose goal is to improve U.S. competitiveness through collaborative R&D. The group decided to address educational needs of kindergarten through 12th grade, reasoning that resources saved through upgrading the workforce could be invested in other areas critical to industry survival and success.

In 1992 the Center introduced the mobile Manufacturing Technologies Laboratory (MTL), a program that takes technology education to students. One of these units is now on the road, another is almost ready to roll, and a third is being designed.

The working unit is the Materials Removal Laboratory, containing a milling machine, a lathe, a robot, a laser trainer, 486/33 DEC computers, and computer-aided design and manufacturing (CAD/CAM) software [see opposite page]. A prototype exists of the Electronics Lab, complete with surface-mount technology gear, a hypercard-based tutorial, a screen printer, a pick-and-place robot, an inspection station, a solder reflow oven, an ultrasonic cleaning station, and a through-board soldering station. In the design stage is the Materials Forming Laboratory, which will work with metal and plastic materials.

The laboratories are supported by a modular curriculum developed by experts in technology education working with industry under the direction of NCMS. The modules are written at middle-school level and are intended to induce students to choose math- and science-related high school classes.

MODULAR DEVELOPMENT. Twelve modules have been developed: CAD, CAM, computerized numerical control (CNC), robotics, lasers, logos, packaging, biosphere, habitat, structures, anthropometry, and time. Under development are modules covering symbology, polymers, waste watchers, manufacturing, satellite communication, and ergonomics. The modules, which use problem-solving methods, include systems theory, adopt an interdisciplinary approach, and require hands-on activities to be conducted in both the lab and the classroom.

For example, in the CNC machining module, the knowledge students are expected to gain includes the ability to describe how CNC is different from manual machining, to identify the *X*, *Y*, and *Z* axes used in CNC milling, to explain the difference between absolute and incremental programming, and to understand how codes are used to communicate between humans and machine. Students are asked to work out problems using the Cartesian coordinates of various objects on a grid, and to use a few basic machine codes.

Each lab spends two to three weeks at a school. Students typically spend an hour a day in the lab, in groups of six to eight. They are tested before and after their lab experience, to determine the effect of the program on their understanding.

The program also trains teachers in current technology and in the skills required for success at work. Support here includes in-service workshops, teacher guides, reference materials, and ongoing conferences and workshops.

The cost of the program varies with the lab involved. For example, the Materials Removal Laboratory costs $350 000, of which the center's industry sponsors contribute $200 000 and the community the rest. Operating costs (including the lab operator's salary) are estimated at $50 000 annually. The lifespan of each unit is expected to be 10 years, but the center plans to update the equipment before that time elapses; NCMS helps the schools obtain low-cost equipment, and also helps them find funding for it.

Funding is flowing in from a variety of sources. The center is applying for Federal funds. Individual states have expressed interest, and bills have been written in some to include the laboratory program in the state budget. Private and corporate foundation officials are responding favorably to the program, though the fundraising effort is still nascent. In some cases, funding is available from state and Federal education budgets.

ON THE ROAD. During the last school year, students in Washtenaw County, MI, took part in a pilot test. Many students, teachers, and parents responded positively to this test. According to one science teacher, "I have to literally throw them out at the end of the day—even students who have shown very little interest in classroom work love this lab." The principal of a middle school during the test received a call from a parent asking, "What exactly are you doing in that lab? My daughter chose to come to school instead of going on a family outing to the beach this Friday because she was having so much fun there."

And a ninth-grader, with his hands on the keyboard programming the milling machine during the pilot test, exclaimed, "Now I understand what *X*, *Y*, and *Z* coordinates have to do with each other—I had no idea during my whole algebra class how I would ever use that kind of information." And several teachers commented that they were happy to have a chance to learn how today's technology worked and to see what is currently being done in an industrial setting.

This September, students in South and Central Texas, through the Lower Rio Grande Tech Prep Consortium in Harlingen and the Austin Independent School District, respectively, will be the first to join the MTL program. The hope is to reach 10 percent of the United States' 41.5 million precollege students by the year 2000, with some 10 000 laboratories.

Globally, the United States is playing catch-up with some of its trading partners in Europe and Asia that have a history of providing their young people with applications-based education programs. Germany and Britain have apprenticeships for students who decide to opt out of university-bound programs. Japanese schools provide hands-on learning experiences from the elementary grades on. The Manufacturing Technologies Laboratory program is a start in offering U.S. students opportunities that are similar to those from which students in other countries have long benefited.

ABOUT THE AUTHOR. Robert F. Johnson (M) is worldwide learning services marketing manager at Digital Equipment Corp, Stow, MA. He has been with Digital for the last 14 years.

A preview of the 21st century

Where is the world of manufacturing heading? Manufacturing is a prime generator of wealth and is critical in establishing a sound basis for economic growth. Socioeconomic changes have, however, generated such internationally shared phenomena as the globalization of corporate activities and changes in market requirements, particularly the need for a shorter lead time in production. There are also common concerns about the effective utilization of resources, the need to preserve the environment, and the systematic transfer of manufacturing knowledge to the next generation.

To cope with these and related problems efficiently, the international manufacturing community has launched a feasibility study that seeks to establish a framework for an international, collaborative program focusing on such developments as an intelligent manufacturing system (IMS) or next-generation advanced manufacturing technologies. Started in February 1992, the feasibility study is expected to continue until early 1994, when a report on its progress will become available. The organizers believe that continuation of the IMS program beyond that phase will encourage international collaboration on R&D in manufacturing technology, thereby benefiting not only the manufacturing community but mankind as a whole.

Intelligent manufacturing

Hideyuki Hayashi IMS Promotion Center

Manufacturing is the cornerstone of all economic activities, and efforts to continuously advance manufacturing technology are therefore vital to a richer and more stable future.

One such effort is a feasibility study for an international collaborative program to develop next-generation advanced manufacturing technologies.

The roots of the manufacturing system go back a long way. At the beginning of the 20th century, mass production using machine tools first emerged and was established in the United States [see p. 26]. Since the 1950s, new technologies have been developed and introduced, including numerical control, flexible manufacturing systems, and lately, computer-integrated manufacturing (CIM). All these technologies have advanced the economy through scientific systematization and proper processes for disseminating information.

Of late, however, socioeconomic changes have generated a number of problems common to the industrialized nations. These problems, which could threaten the foundation of a country's manufacturing industry, are related to the following phenomena:

- The globalization of corporate activities.
- Changes in human factors, including shortage of skilled labor and the reluctance of young engineers to work in the manufacturing industry.
- Changes in market requirements, including shorter lead time in production and diversified needs.
- Problems due to the need to preserve natural resources and the environment.
- Increased investment required for manufacturing systems and R&D.

Intelligent Manufacturing System (IMS) Program

Technical themes of test cases

Enterprise integration

Keywords
- Modeling
- Systems architecture
- Network systems
- Database technologies
- Product design technologies
- Product data exchange technologies

Global manufacturing

Keywords
- Concurrent engineering
- Organizational and economic aspects
- Supplier and distribution management

System component technologies

Keywords
- Autonomous systems
- Design and simulation
- Sensor and information fusion

Clean manufacturing

Keywords
- Environmental safety
- No waste
- Energy conservation

Human and organizational aspects

Keywords
- Human-oriented production systems
- Human-machine interaction
- Internal and external teamwork

Advanced materials processing

Keywords
- Machining
- Forming
- Complex processing
- Process modeling and simulation

Globalization presents particular problems because, depending upon the nature and purpose of its activities, a company may have various facilities located around the world. To manage those facilities effectively, and to handle its policy making and production planning, a company needs a communications network that interconnects its multiple manufacturing plants and sales offices, as well as other facilities. Setting up such a network is essential for exchanging data through an internationally compatible communications system.

Increasingly, companies are finding they need a common intercompany communications system that enables different firms to exchange information. As the barriers between different areas of manufacturing diminish, companies are interacting with one another to a greater degree, and this interdependence is well on the way to intimacy. At present, though, it is seldom easy to exchange manufacturing information, because of systems incompatibility.

In addition, capital and goods nowadays move through world markets more freely, and technological innovations occur faster than ever. Critical to this worldwide activity is the solution to a certain set of problems—those caused by delays in disseminating information on innovations. A speedy transfer of manufacturing technologies is essential to the sound development of manufacturing industry throughout the world.

Recognizing the importance of these problems, Japanese experts from industry and academia initially proposed the IMS international collaborative program in 1989, and the Japanese government supported it. Hiroyuki Yoshikawa, now president of the University of Tokyo, headed the effort. It was planned to cover such advanced manufacturing technological areas as components, management and control, system design, and human factors and environment.

The three key R&D objectives were to conduct basic research in basic and next-generation technology; to organize and systematize the knowledge so it could be used in developing new technology and facilitating its transfer; and to standardize all such technology.

This program is a first because it aims at

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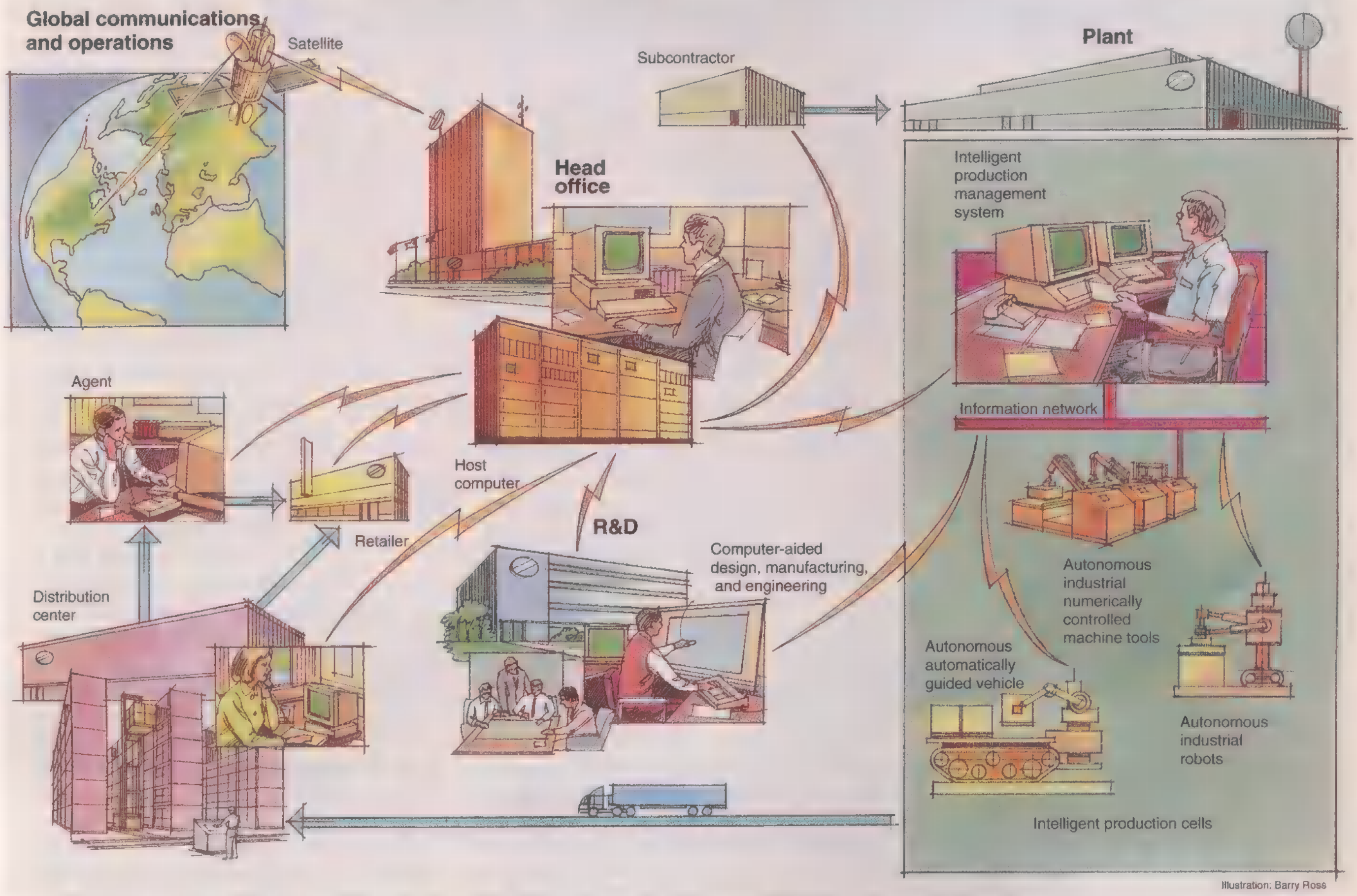
Vision of a future intelligent manufacturing system



Future plants based on the intelligent manufacturing system concept are expected to include such distributed, autonomous, and intelligent systems as industrial robots, numerically controlled machine tools, and automated guided vehicles—all interacting with an intelligent production management system. Computer-aided design, manufacturing, and engineering at an R&D center will help in the rapid development of new products matched to customers' needs, which forms concurrent engineering. A global communications network with standardized interfaces will link the head office to the manufacturing plants, sales agents, and subcontractors.

joint international research in manufacturing. Although joint research has been done before in a few fields like aircraft design and construction, international cooperation in manufacturing, including the targeting of technical fields on a large scale and multinational participation, is unprecedented.

Under the Japanese proposal, the IMS will be a next-generation, flexible manufacturing system that will integrate the entire spectrum of manufacturing activities—from research and development through order booking, design, manufacturing, distribution, and management [see illustration].

Since the IMS program was first proposed, many countries have shown their interest by involving experts from industry and academia in discussions and by taking part in informal meetings among governments. As a result, all the interested parties have agreed on doing an international feasibility study of how and by what means to collaborate on research in advanced manufacturing technology.

In December 1991, Australia, Canada, the European Community, five countries of the European Free Trade Association (EFTA), Japan, and the United States agreed to the Terms of Reference for a Feasibility Study on International Collaboration in Advanced Manufacturing. The study is based on the following five principles:

- Manufacturing is a primary generator of wealth and is critical to establishing a sound basis for economic growth.
- Greater sophistication in manufacturing operations is required in global markets.
- R&D in advanced manufacturing is becoming increasingly pivotal to manufacturing operations.
- Substantial advanced manufacturing research is being carried out worldwide.
- Properly managed international collaboration on this research could improve manufacturing operations.

EQUITABLE GOAL. The feasibility study aims at developing and testing a framework for international collaboration and, more importantly, at proving whether an international collaborative program in this area can be created and structured equitably and beneficially.

The study has two phases. One is a study phase aimed at examining and developing a structure for such a program, including issues like modalities and funding arrangements for international collaboration, technical themes for a future program, and guidelines for intellectual property rights (IPR). The other is an R&D test case phase in which enough test cases are to be carried out to provide empirical data for the study phase.

By common consent, the feasibility study has been organized and is managed by three committees—the International Steering Committee, the International Technical Committee, and the International Intellectual Property Rights Committee. These comprise high-level industrial and academic experts with administrative secretariats in each region. Currently functioning as secretariats are Australia's Department of Industry, Technology and Regional Development; Canada's Department of Industry, Science and Technology; Directorate General-III of the Commission of the European Communities; Japan's Ministry of International Trade and Industry; and the U.S. Department of Commerce. (DG-III performs this role for the European Community and five

IMS test cases and regional lead partners

Test case	Australia	Canada	European Community	EFTA	Japan	United States
Clean manufacturing in the process industry	—	Abitibi-Price	ICI Engineering	Finnish Forest Industries Federation	Toyo Engineering Corp.	Du Pont Co.
Global concurrent engineering	—	Northern Telecom	Technology Transfer PLC	—	—	North Carolina State University
Globeman 21: enterprise integration for global manufacturing toward the 21st century	CSIRO	Toronto University	British Aerospace Defense Ltd.	Ahlstrom Machinery	Toyo Engineering Corp.	Newport News Shipbuilding & Dry Dock Co.
Holonic manufacturing systems: system components of autonomous modules and their distributed control[a]	Broken Hill Proprietary & Co.	Queens University	Softing GmbH	Softing GmbH	Hitachi Ltd.	Allen-Bradley Co.
Rapid product development	Moldflow Pty Ltd.	Pratt & Whitney Canada Inc.	Daimler-Benz AG	—	—	United Technologies Corp.
Knowledge systematization: configuration systems for design and manufacturing—Gnosis	—	Alberta Research Council	Adepa	ABB Asea Brown Boveri	Mitsubishi Electrical Corp.	Deneb Inc.

Adepa = Agence de la Productique; CSIRO = Commonwealth Scientific and Industrial Research Organization; EFTA = European Free Trade Association; Gnosis = Systematization of manufacturing knowledge.
a Holonic describes a highly cooperative group of machines.

countries of the European Free Trade Association.)

The feasibility study began in February 1992 and is expected to take about two years. During the first year, because of limited time, most effort addressed test case development. The IMS committees reviewed modalities, technical themes, and IPR guidelines of relevance to test cases. These issues were carefully determined, and test case proposals were requested in July last year.

Such entities as large and small companies, both suppliers and users, and universities and research institutions were encouraged to form consortia and take part. It is from these consortia that contributions to the development of the framework of the IMS program are expected.

In setting guidelines for modalities for the test cases, the International Steering Committee specified that consortia in test cases should contain partners from at least three regions of the world; collaborative projects should have industrial relevance; and contributions to, and benefits from, such collaboration should be equitable and balanced.

It also stipulated that research should be carried out by consortia that are geographically distributed and decentralized, and that projects benefiting from governmental sponsorship or resources should involve precompetitive R&D. Also, each region should determine its funding mechanism.

In selecting the technical themes, the committees made sure that each theme has associated meaningful keywords [see table, p. 82]. They set the six following themes: enterprise integration, global manufacturing, system component technologies, clean manufacturing, human and organizational aspects, and advanced materials processing. The committees also requested that a test case be compatible with a portion of the scope defined by these technical themes and that it be related to the program's key objectives of R&D, standardization, or systematization of knowledge.

PARTNERS AND PATENTS. The committees further agreed that to protect, utilize, and disseminate the technical information created in a test case, it was imperative to offer IPR guidelines to partners in a consortium. The guidelines specify that:

- Patents, copyrights, and other intellectual property rights generated in the project shall be owned by the partner creating it.
- The other partners in the project shall have a royalty-free license of the intellectual property rights from the partner creating it.
- Summary information of the project shall be available to all partners in other projects.

More than 500 companies and universities expressed an interest in participating in test cases. Despite the short notice, 11 applications for test cases were submitted to the regional secretariats.

After the respective committees had sifted through them, six of the 11 were selected as test cases at the end of last January and the consortia were asked to begin their work as soon as possible [see table, above]. These projects, which will run for a year, typically involve cooperation of four or five regions, with a total of 140 industrial partners worldwide, including universities and research institutes.

With the test cases begun, the feasibility study has entered a new stage: detailed discussions on the framework of a future program.

Currently, the international technical and IPR committees are monitoring what each consortium is doing. They are also reviewing technical themes and IPR guidelines for a future program. The International Steering Committee has also started discussions on future program issues, providing direction to the other two committees.

This April, the International Steering Committee meeting held in Kyoto, Japan, issued a common understanding statement. In part, it said: "It is expected that each region will make its own decision to participate in a full-scale program based on recommendations at the completion of the IMS feasibility study in early 1994.

"It is time to take action on internationally common issues, including global environmental problems, effective utilization of resources, improvement in the quality of industrial life, globalization of manufacturing, and efficient transfer of manufacturing knowledge to the next generation.

"A well-balanced regime for international R&D collaboration in intelligent manufacturing could contribute to the development of the world economy. The IMS program could provide an effective mechanism to resolve common problems, and expand open markets around the world.

"Recognizing the above, the International Steering Committee expressed its intention to promote harmonized international relations through its work on a possible full-scale IMS program. The committee encourages entities in all six regions to consider the positive experiences gained through the IMS feasibility study with a view to participation in the IMS program, if ratified."

The final report of the feasibility study is to be prepared early next year. It is expected, however, that a future IMS program will further encourage international collaboration in R&D, and bring extensive benefits to those directly involved in manufacturing and to mankind as a whole.

ABOUT THE AUTHOR. Hideyuki Hayashi is senior executive director, IMS Promotion Center, International Robotics and Factory Automation Center in Tokyo.

To probe further

FLEXIBILITY. *IEEE Transactions on Robotics and Automation* regularly covers such topics as the simulation of robots and manufacturing systems. Contact the IEEE Customer Service Department, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 1-800-678-IEEE (United States), 908-981-0060 (elsewhere); fax, 908-981-9667.

QUALITY. *The automated factory handbook: technology and management*, by David I. Cleland and Bopaya Bidanda, discusses the management of quality (TAB Books, Blue Ridge Summit, PA, 1990).

EFFICIENCY. A video tutorial, *Beyond concurrent engineering* (No. HV0236-0-PVB), discusses practical approaches to concurrent engineering. Presented by Michael Dick, et al., it can be ordered from the IEEE Customer Service Department. Charles Savage addresses *Fifth Generation Management: Integrating Enterprises through Human Networking* (Prentice Hall, New York, 1990).

Industrial Engineering, a monthly published by the Institute of Industrial Engineers, 25 Technology Park/Atlanta, Norcross, GA 30092, 404-449-0460, covers simulation and modeling in manufacturing and also reviews relevant software.

Averill M. Law and David Kelton discuss *Simulation, Modeling and Analysis* (McGraw-Hill, New York, 1981).

The 1993 Winter Simulation Conference (WSC '93), Dec. 12–15, Los Angeles, CA, will address topics relevant to manufacturing plant modeling and simulation. Contact the IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

ENVIRONMENT. Environmental issues will be among the topics discussed in the 15th International Electronic Manufacturing Technology Symposium, Oct. 4–6, 1993, Santa Clara, CA, sponsored by the IEEE's Components Hybrids and Manufacturing Technology Society and the Electronic Industries Association. Contact Al Blodgett, IBM Corp., 1580 Route 52, Hopewell Junction, NY 12533; 914-894-5018; fax, 914-894-3081.

ECONOMY. "Lean production" is the popular term devised by the MIT Automobile Project to describe the Toyota production system and then adopted by James P. Womack, Daniel T. Jones, and Daniel Roos in their book *The Machine That Changed the World* (Rawson Associates, New York, 1990).

The role of technology in manufacturing is the subject of Paul M. Swamidass's monograph *Technology on the Factory Floor* (National Association of Manufacturers, Washington, DC, 1992).

GOVERNMENT AND INDUSTRY SUPPORT. Japan's small-firm sector is reviewed in Takashi Yokokura's chapter on "Small and Medium Enterprises" in *The Industrial Policy of Japan*, by Ryutaro Komiya, et al., translated by Sato Kazuo (Academic Press, now in San Diego, 1988). The U.S. congressional Office of Technology Assessment examines Japanese approaches to technology transfer and diffusion for smaller firms in *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (U.S. Government Printing Office, Washington, DC, 1990), GPO Stock No. 052-003-01178-6.

Additional information on state support for U.S. manufacturers is available in a 1991 National Governors' Association report, *Increasing the Competitiveness of America's Manufacturers: a review of state industrial extension programs*, by Marianne K. Clarke and Eric N. Dobson, available from the association at 444 North Capitol St., Washington, DC 20001; 202-624-5300.

The U.S. Navy operates a database documenting successful manufacturing practices in the United States. Contact U.S. Navy, Best Manufacturing Practices Program, 2101 Crystal Plaza Arcade, Suite 271, Arlington, VA 22202; 703-696-8483; fax, 703-696-8480. A similar program for benchmarking the best industrial practices is in progress at the National Electrical Manufacturers Association, 2101 L St., N.W., Washington, DC 20037-1526; 202-457-1975.

EDUCATION. For more on the Manufacturing Technologies Laboratory, contact Helen Dorsey, Director of State and Industrial Relations at the National Center of Manufacturing Sciences; 313-995-0300.

THE FUTURE. The Intelligent Manufacturing System program has six regional secretariats, listed below.

- Australia: Manufacturing and Materials Technology, Heavy Industries Division, Department of Industry, Technology, and Regional Development (Ditac); (61+6) 276 1181; fax, (61+6) 276 1607.
- Canada: Dennis Shanley, IMS coordinator, Advanced Manufacturing Technology, Industry & Science Canada; 613-954-3247; fax, 613-914-2463.
- The European Community: Directorate General-III, F6, Industrial Affairs; (32+2) 296 8138; fax, (32+2) 296 8365.
- The European Free Trade Association: Technology Development Centre of Finland; (358+0) 694 9196; fax, (358+0) 6936 7794.
- Japan: Industrial Machinery Division, Machinery and Information Industries, Ministry of International Trade and Industry; (81+3) 3501 2805; fax, (81+3) 3580 6394.
- U.S.: Andy Wan, Japan Technology Program, Room H4817, Commerce Department; 202-482-0151; fax, 202-482-4826.

Discussions of advanced technologies for industrial automation will be held at IECON '93, 19th Annual IEEE Conference on Industrial Electronics, Nov. 15–19, Maui, HI. Contact Robert J. Roman, 3685 Oak Rim Way, Salt Lake City, UT 84109; 801-277-1456; fax, 801-223-1456.

Acknowledgments

IEEE Spectrum called upon many experts in preparing this special issue, although their identification with it should not be construed as an endorsement of these materials. We are especially indebted to the following consultants for their advice: M. Dayne Aldridge, Thomas Walter Center for Technology Management, Auburn University, AL; Eric Bloch, Distinguished Fellow, Council on Competitiveness, Washington, DC; Lloyd M. Cooke, president, LMC Associates, White Plains, NY; Fumio Harashima, director, Institute of Industrial Science, University of Tokyo; J. P. Hurault, senior director, Philips Research Laboratories, Eindhoven, the Netherlands; Timothy L. Johnson, manager, control design and product development program, General Electric Co., Corporate Research and Development, Schenectady, NY; Russell C. Lange, director, Manufacturing Research Department, IBM Corp., Thomas J. Watson Research Center, Yorktown Heights, NY; Dan Maas, program manager, manufacturing processes and materials, National Center for Manufacturing Sciences, Ann Arbor, MI; Colin Maunder, engineering advisor, Telecom Research Laboratories, Martlesham Heath, Ipswich, England; James D. Meindel, senior vice president for academic affairs and provost, Rensselaer Polytechnic Institute, Troy, NY; Dennis R. Olsen, manager, R&D Prototype Laboratory, Motorola Inc., Phoenix, AZ; Fred Pool, miniaturization specialist, Center for Manufacturing Technology, Nederlandse Philips Bedrijven B.V., Eindhoven, the Netherlands; Daniel P. Siewiorek, professor of computer science, Carnegie Mellon University, Pittsburgh; Odo J. Struger, vice president of technology, Allen-Bradley Co., Highland Heights, Ohio; T.J. Tarn, professor of systems science and math, Washington University, St. Louis, MO; Alfred C. Weaver, professor, Computer Science Department, University of Virginia, Charlottesville; Daniel E. Whitney, principal engineer, The Charles Stark Draper Laboratory Inc., Cambridge, MA; Michael F. Wolff, contributing editor, New York City; Lawrence P. Grayson, director, postsecondary relations staff, U.S. Department of Education, Washington, DC.

Last but not least, the issue editor thanks his son, Adam E. Kaplan, for helpful suggestions.

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Awards 93

Corporate Recognition

JPL Director Edward C. Stone

The Jet Propulsion Laboratory (JPL) has been presented with an IEEE Corporate Recognition "for contributions to electrical, electronic, and computer engineering that have led to preeminence in the unmanned exploration of space."

A division in Pasadena, CA, of the California Institute of Technology and a National Aeronautics and Space Administration (NASA) center, JPL is one of the premier organizations in the world dedicated to unmanned planetary exploration. It has pioneered in both the theory and practice of electrical and electronics engineering, while providing instrumentation rugged enough to withstand propulsion into space and function reliably for decades.

JPL's innovations, sometimes made in collaboration with industry and academia, include many pioneering efforts: computerized image enhancement and photo mosaicking; Viterbi decoding; video cameras operating in space at 0.001 of the light levels on earth; the use of parallel computing for generating topographic movies from still, two-dimensional images; autonomous and reprogrammable on-board computing; radar contact with a planet; spaceborne synthetic-aperture radar; space terminal guidance, and a worldwide network for tracking objects in space. The work enhanced theory and practice in several areas, including communications and signal processing, applied electromagnetic theory image processing, and photovoltaics.

Edward C. Stone, director of the laboratory, a vice president of the California Institute of Technology, and a professor of physics, accepted the recognition for JPL. He has been project scientist for the Voyager Mission to the outer planets since 1972. He is a member of the National Academy of Sciences, Washington, DC, and the International Academy of Astronautics, Paris, France, and he has been awarded the National Medal of Science and numerous NASA medals.

Engineering Leadership Recognition

Percy N. Barnevik

Percy N. Barnevik, president and chief executive officer of ABB Asea Brown Boveri, received an IEEE Engineering Leadership Recognition "for managerial leadership in creating a global enterprise in the areas of electric power apparatus and systems, transportation, and environmental technologies."

Barnevik was president and chief executive officer (CEO) from 1980 to 1987 of the Swedish-based electrical engineering group Asea. In that time, restructuring and concentration on focused R&D, together with international business development efforts, pushed annual sales from US $2 billion to $9 billion, making the company a worldwide leader in such areas as robotics, high-voltage direct current, and fluidized-bed combustion used for power plants.

In 1988, Barnevik was named president and CEO of the merged ABB Asea Brown Boveri. Internal growth and some 75 acquisitions brought the company from about $18 billion to more than $30 billion in annual sales. The company has 65 business areas operating in more than 100 countries run through 1300 legal entities.

ABB calls itself "multi-domestic" and strives to combine national identity with global management. With its 5000 profit centers, it also strives to combine being small with being big. In recent years the giant company has become well known for creating a common corporate culture aimed at reducing cycle times everywhere and raising quality levels as well.

Of late, Barnevik has been heavily involved in efforts to support development in the former Soviet bloc countries, including the application of Western technology to ailing nuclear power plants. ABB is one of the biggest Western investors there and has 25 000 employees in these countries.

Barnevik has also encouraged the continuing education of EEs and, in ABB management seminars offered worldwide, has passed on his ideas and visions. Awarded a master's of business administration degree from the Götenburg School of Economics in Sweden in 1964, Barnevik also studied business and computer science at Stanford University in California.

Service awards

For furthering the IEEE's technical objectives and for rendering outstanding service to the Institute, William R. Tackaberry (LS) and Harold S. Goldberg (LF) have received the IEEE's 1993 service awards.

Tackaberry, who retired in 1981 as vice president, General Electric Co., Fairfield, CT, received the Richard M. Emberson Award "for widespread activity in the power engineering field, as well as United States technology policy, and the general administration of the IEEE."

Tackaberry joined GE in 1939 as a test engineer and, except for several years during World War II, spent his 41-year career there. He held jobs relating to the electric utility industry, becoming general manager of power transmission and distribution sales and a vice president in 1968.

He served as a vice president of the U.S. National Committee of Cigré (the international conference of large high-voltage electric systems), and as a delegate to its international administrative council. Between 1983 and 1987, he served on the Power Engineering Society's Executive Committee, and in 1986 Division VII—Energy and Power Engineering—elected him to the IEEE Board of Directors. Other IEEE positions included chair of IEEE-USA's Technology Policy Council, vice chair of the Technical Activities Board, and board member of numerous committees.

Goldberg, associate dean, Gordon Institute, Wakefield, MA, received the Haraden Pratt Award "for leadership in Society technical, regional, and professional programs, and for his unifying contributions to the Institute's overall programs."

William R. Tackaberry

Harold S. Goldberg

Goldberg began his career as a design engineer developing military and commercial instrumentation. He directed engineering groups at Dumont Laboratories and Emerson Radio, and was chief engineer at Consolidated Avionics and Epsco. He co-founded Data Precision Corp. in 1971, serving as its president until 1982. Before then, when Data Precision merged with Analogic Corp. in 1978, Goldberg became a vice president of Analogic as well. In 1984 he left that post in order to help found Acrosystems Corp. He has been associate dean of the Gordon Institute of Tufts University since 1988.

He became Boston Section chair in 1971 and a year later Region 1 Director and a member of the IEEE Board of Directors. He was the Institute's first Vice President–Professional Activities. In 1986, Goldberg became president of the Instrumentation and Measurement Society, and in 1989 he was again elected to the IEEE Board, as Director of Division II. All told, he spent 13 years on the Electro Show's Board of Directors, as well as on numerous other committees and boards. ◆

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Since the invention of the telephone, we've dreamed of communication with no barriers. At Motorola Satellite Communications, that dream is reality...with **IRIDIUM** TM/SM — a global, personal commmunications system combining sophisticated satellite and cellular technology.

The technological and professional challenges are unprecedented. And Motorola in Phoenix, AZ is the only place offering these exciting opportunities, in key technical leadership positions. Appropriate technical degree and 9 years related experience are desired for the following openings:

Software Process/Subcontract Management — Responsible for software process improvement related to the evaluation of software suppliers as well as for acquisition of COTS and subcontracted software. Working knowledge of the SEI Software Capability Maturity Model and software supplier management experience highly desirable. Training in process assessment would be a plus.

Staff Electrical Engineer — With responsibility for verification of processing subsystem, you will define overall data base of packets and means to automatically generate different packet sets, verify processor design, aid in ASIC testing and support system testing. This is a high level VHDL functional simulation of a single chain data path using IKOS Voyager.

Software Independent Verification & Validation Engineers — Requires large, distributed software systems IV&V experience to monitor and evaluate development/integration. Direct large communications systems experience, including systems/software engineering techniques, is essential. Software management and/or IV&V experience and strong leadership skills are highly desired.

Software Integration & Test Engineers — Help establish/maintain two heterogenous SVR4 distributed computing environments, as well as develop test plans, procedures and software. Experience with Solaris 2.x, NIS+, shell scripts and "C" required. Experience with AIX, C++, TIVOLI, relational databases and object-oriented methodologies strongly desired.

System Test Manager — Define program test requirements and develop detailed plans for system Integration and Testing. Will manage procedure development, STE development, test software development, and test execution. Prefer experience with incremental development of large software systems.

Paging Systems Engineer — Establish requirements, architecture and preliminary design for paging infrastructure equipment. Familiarity with Motorola paging systems or Ermes Standards for digital paging required; prefer experience with international paging systems, including systems integration, installation and fielding of paging systems.

Protocol Engineers — Develop self-consistent protocols for entire network. Requires telecom protocol development experience including SS7 and ISUP, ISDN, Transmission System Protocols, intelligent networks, GSM and IS-41 Cellular Protocol Standards.

With year-round recreational activities, beautiful scenery and low housing costs, you'll also find our Phoenix location a dream come true. To find out all we have to offer, including our excellent compensation and benefits, get in touch with us soon. An Affimative Action Employer. Minorities, Women and Disabled Persons are strongly encouraged to apply. Principals only, please.

Please mail your resume with salary history to: **Professional Recruitment, Motorola Satellite Communications, Dept. B1274, 8201 E. McDowell Rd., Scottsdale, AZ 85252.**

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MOTOROLA

Satellite Communications

Yesterday's dream. Today's reality.

Calendar

(Continued from p. 12)

Symposium on Experiences with Distributed and Multiprocessor Systems IV (C); Sept. 23–24; Hilton Beach Tennis Resort, San Diego, CA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

15th Annual Electrical Overstress/Electrostatic Discharge Symposium—EOS/ESD (CHMT); Sept. 26–27; Buena Vista Palace, Lake Buena Vista, FL; EOS/ESD Association Inc., 200 Liberty Plaza, Rome, NY 13440; 315-339-6937.

Holm Conference on Electrical Contacts (CHMT); Sept. 26–29; Pittsburgh Vista, Pittsburgh; Holm Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3895; fax, 908-562-1571.

Third International Workshop on Photonic Networks, Components, and Applications (LEO, COM); Sept. 26–29; Westin Peachtree Plaza, Atlanta, GA; Kathy Mahoney, Conference Registrar, Photonics '93, 340 March Rd., Suite 400, Kanata, ON K2K 2E4, Canada; 613-592-8160; fax, 613-592-8163.

Second International Workshop on Emerging Technologies and Factory Automation—ETFA '93 (IE et al.); Sept. 27–29; Palm Cove Resort, North Queensland, Australia; Alfred C. Weaver, Department of Computer Science, Thornton Hall, University of Virginia, Charlottesville, VA 22903; 804-982-2201.

Application Specific Integrated Circuits Conference and Exhibit (C, Rochester Section); Sept. 27.–Oct. 1; Rochester Riverside Convention Center, NY; Lynne M. Engelbrecht, ASIC Seminar Coordinator, 1806 Lyell Ave., Rochester, NY 14606; 716-254-2350; fax, 716-254-2237.

International Symposium on Subscriber Loops and Services (COM); Sept. 27–Oct. 1; Vancouver Trade and Convention Center, BC, Canada; Shahid Hussain, BC Tel, 2-4535 Canada Way, Burnaby, British Columbia V5G 1J9, Canada; 604-654-7420; fax, 604-654-7447.

Wescon '93 (Bay Area C, LA Council); Sept. 28–30; Moscone Convention Center, San Francisco; Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045-3194; 800-877-2668; fax, 310-641-5117.

OCTOBER

International Conference on Computer Design: VLSI in Computers and Processors (ED); Oct. 3–6; Royal Sonesta Hotel, Cambridge, MA; IEEE Computer Society, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Industry Application Society Annual Meeting (IA); Oct. 3–8; Royal York Hotel, Toronto; Ajit Bapat, Federal Pioneer Ltd., 19 Waterman Ave., Toronto, ON M4B 1Y2, Canada; 416-752-8020; fax, 416-752-6230.

Bipolar/BiCMOS Circuits and Technology Meeting (ED); Oct. 4–5; Minneapolis Marriott City Center Hotel, MN; John Shier, VTC Inc., 2800 E. Old Shakopee, Bloomington, MN 55425; 612-853-3292; fax, 612-853-3355.

15th International Electronic Manufacturing Technology Symposium (CHMT); Oct. 4–6; Marriott Hotel, Santa Clara, CA; Al Blodgett, IBM Corp., 1580 Route 52,

Hopewell Junction, NY 12533; 914-894-5018.

Electrical/Electronics Insulation Conference (DEI); Oct. 4–7; Rosemont Convention Center, Chicago; Frank McGuinn, Box 35395, Minneapolis, MN 55439; 612-942-7388; fax, 612-942-7389.

Workshop on Distributed Systems: Operations & Management (COM); Oct. 5–6; Ocean Place Hilton, Long Branch, NJ; Dorotea DeSan, AT&T Bell Laboratories, Room 16-314, 101 Crawfords Corner Rd., Holmdel, NJ 07733; 908-949-5534.

International Conference on Semiconductor Electronics (ED); Oct. 5–7; Kuala Lumpur Hilton, Kuala Lumpur, Malaysia; Zahari M. Darus, Department of Electrical, Electronic, and Systems Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia; (60+3) 825 1292; fax, (60+3) 825 9080.

International SOI Conference (ED): Oct. 5–7; Autry Resort, Palm Springs, CA; John Schott, USAF RADC/ESR, Hanscom AFB, MA 01731; 617-377-3817.

International Professional Communication Conference—IPCC '93 (PC); Oct. 6–8; Hotel Atop the Bellevue, Philadelphia; Michael B. Goodman, Fairleigh Dickinson University, Madison, NJ 07940; 201-593-8709; fax, 201-593-8510.

Gallium Arsenide Reliability Workshop (ED); Oct. 10; Fairmont Hotel, San Jose, CA; Anthony Immorlica, General Electric Co., Electronics Park 3-102, Syracuse, NY 13221; 315-456-3514; fax, 315-456-0695.

GaAs IC Symposium (ED); Oct. 10–13; Fairmont Hotel, San Jose, CA; Paul R. Jay, Bell-Northern Research, Box 3511, Station C, 3500 Carling Ave., 5C20 Ottawa, ON K1Y 4H7, Canada; 613-763-2363.

Military Communications Conference—Milcom '93 (COM, Boston Section); Oct. 11–14; Stouffer Bedford Glen Hotel, Bedford, MA; Anthony A. Rutti, GTE Government Systems Corp., 77 A St., Building 23, Needham Heights, MA 02194; 617-455-4805; fax, 617-455-5734.

15th Symposium on Fusion Engineering (NPS); Oct. 11–15; Tara Hyannis Hotel & Resort, Hyannis, MA; Dori Barnes, Conference Publicity, Princeton Plasma Physics Laboratory, Box 451, Princeton, NJ 08543; 609-243-2557; fax, 609-243-3086.

Northcon '93 (Seattle Section); Oct. 12–14; Oregon State Convention Center, Portland; JoAnn Lindberg, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668.

Vehicle Navigation & Information Systems Conference (AES, VT, et al.); Oct. 12–14; Ottawa Congress Centre, Ottawa, ON, Canada; D. Hugh M. Reekie, VNIS '93, Box 3083, Station D, Ottawa, ON K1P 6H7, Canada; 613-990-4099; fax, 613-998-7008.

International Conference on Universal Personal Communications (COM, et al.); Oct. 12–15; Westin Hotel, Ottawa, ON, Canada; Vino Vinodrai, Bell Mobility Cellular, 20 Carlson Court, Etobicoke, ON M9W 6V4, Canada; 416-798-5039; fax, 416-674-6211.

International Workshop on Rough Sets and Knowledge Discovery (Region 7); Oct. 12–15; High Country Inn, Banff, AB, Canada; Wojciech Ziarko, Computer Science Department, University of Regina, Regina, SK S4S 0A2, Canada; 306-585-5213; fax, 306-585-4745.

Fourth International Conference on Foundations of Data Organizations and Algorithms (C); Oct. 13–15; Orrington Hotel, Evanston, IL; IEEE Computer Soci-

The Saudi Consolidated Electricity Company in the Western Region (SCECO-West), Jeddah, Saudi Arabia, invites applications for the following positions. Attractive salary, medical coverage, and other benefits to the suitable candidates will be given according to qualifications and experience. Applicant should send to our company his C.Vs. and a latest photograph along with the copies of his certificate/degrees (educational qualifications as well as practical experience) within three weeks from the date of its publication on the address given below:

Manager
Personnel Department
Electricity of Western Region (Head Office)
Recruitment Section
P.O. Box No. 9299
Jeddah 21413
Saudi Arabia

Group V = Designs & Specifications Department:

1. Engineer for Steam, Gas and Combined Cycle PowerPlants.
Minimum Qualification: Bachelor in Mechanical.
Experience: 10–15 years experience in the field of projects or construction regarding Steam, Gas and Combined Cycle Power Plants with Power Utility or reputable consultants. He should also be conversant with modern computerized fire detection and alarm as well as fire fighting system.

2. Engineer for 380 KV and 100 KV Sub-Stations.
Minimum Qualification: Bachelor in Electrical Engineering.
Experience: 10 to 15 years experience in the field of Electrical Projects or Construction pertaining to 380 KV and 110 KV GIS sub-stations with Power Utility or some reputable engineering consultants. He should also be conversant with modern computerized fire detection and alarm as well as fire fighting system.

3. Engineer for 380KV and 110KV Overhead Transmission Lines.
Minimum Qualification: Bachelor in Electrical Engineering.
Experience: 10 to 15 years experience in the field of electrical projects or construction pertaining to 380KV and 110KV Overhead transmission lines with power utility or some reputable engineering consultants. In addition to the required experience indicated in the annexed sheet, he should have adequate experience for the following works:
- Selection of most appropriate line routes and tower spotting.
- Selection of most appropriate conductor sizes.
- Preparation of drawings regarding line route, profiles.
- Calculation of weight of towers from their drawings.
- Testing of prototype towers.

4. Civil Engineer for Sub-Station/Power Station.
Minimum Qualification: Bachelor in Civil Engineering.
Experience: Minimum 15 years experience regarding building and foundations of power plants/substations and other associated civil engineering works (such as service roads, concrete ducts, water storage tanks, fuel storage tanks etc.) with power utility or some reputable engineering consultants.

5. Instrumentation and Control Engineer for Transmission System and Power Stations.
Minimum Qualification: Bachelor in Electrical Engineering.
Experience: 15 to 20 years experience in the field of controls and instrumentation pertaining to GIS Sub-stations, outdoor sub-stations and power stations (i.e. steam, gas and combined cycles plants) with power utility or some reputable engineering consultants. He should be well conversant with microprocessors and computerized systems which are in use in modern large power utilities regarding control and instrumentation.

6. Senior Transmission Engineer for 380KV and 110KV Sub-Stations, Overhead Transmission Lines and Underground Cables.
Minimum Qualification: Bachelor in Electrical Engineering.
Experience: Minimum 20 years experience in the field of electrical projects pertaining to 380KV and 110KV GIS sub-stations, outdoor sub-stations, overhead transmission lines as well as underground cables with power utility or some reputable engineering consultants.

General Experience for All the Engineers

- Active participation in the preparation of basic design report and relevant drawings, layouts etc.
- Active participation in the preparation of technical specifications, bill of quantities, drawings and tender documents for the award of the turn-key contracts for complete design, procurement, manufacture, erection, testing and commissioning.
- Tender Evaluation.
- Checking and approval of drawings and technical literature submitted by manufacturer or contractor.
- Witnessing testing of electrical equipment (such as circuit breakers, power transformers etc.) in the manufacturer's factory or in some independent laboratory.
- Supervision of erection of equipment.
- Complete testing and commissioning of equipment.
- Preparation of progress bar charts and CPM (i.e. critical path method) for the project management.

Research Opportunities in Japan

The National Science Foundation offers opportunities for U.S. scientists and engineers to conduct research at Japanese universities, national research institutes, and corporate research laboratories. Support is provided for international travel, living expenses, and other categories depending upon the length of stay in Japan.

To provide these opportunities, NSF cooperates with many Japanese organizations, including the Center for Global Partnership, the Science and Technology Agency, the Agency for Industrial Science and Technology, and the Japan Society for the Promotion of Science. More information on potential host institutions under these organizations is available.

Graduate students, postdoctoral researchers and senior investigators are eligible to apply for research stays in Japan ranging from three to 24 months. The next deadline is November 1, 1993. For more details and application materials please see the program announcement, "International Opportunities for Scientists and Engineers," (NSF-93-51).

To order the program announcement, please contact the Publications Office, National Science Foundation, Washington, D.C. 20550. Tel: (202) 357-3619. TDD: (202) 357-7492. Email: pubs@nsf.gov (Internet) or pubs@nsf (Bitnet).

The program announcement is also available electronically via the Science and Technology Information System (STIS), NSF's online publication dissemination system. For instructions on how to use STIS, please contact stisfly@nsf.gov (Internet) or stisfly@nsf (Bitnet).

For additional details, please contact the Japan Program, Division of International Programs, National Science Foundation, Washington, D.C., 20550. Tel: (202) 653-5862. Email: NSFJinfo@nsf.gov (Internet) or NSFJinfo@nsf (Bitnet).

Calendar

ety, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

International Carnahan Conference on Security Technology (AES et al.); Oct. 13–15; Hotel Plaza de la Chaudière, Ottawa, ON, Canada; Gerry Levett, G. Levett & Associates, RR 3, Spencerville, ON KOE 1XO, Canada; 613-989-3242; fax, 613-989-2940.

Workshop on Speech Coding (COM, SP); Oct. 13–15; Gray Rocks Inn, St. Jovite, PQ, Canada; Lynn Marie Holland, McGill University, 3480 University St., Room 633, Montreal, PQ H3A 2A7, Canada; 514-398-7475; fax, 514-398-4470.

Fourth Workshop on Workstation Operating Systems—WWOS-III (C); Oct. 14–15; Clarion Inn, Napa, CA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Sixth International Conference on Parallel and Distributed Computing Systems—ISCTA (C); Oct. 14–16; Galt House Hotel, Louisville, KY; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013.

Electrical Insulation and Dielectric Phenomena—CEIDP '93 (DEI); Oct. 17–20; Pocono Manor Inn, Pocono Manor, PA; Alan Watson, University of Windsor, c/o Can AM Mailers, 1927 Rosa Parks Blvd., Box 44901, Detroit, MI 48216; 519-253-4232, ext. 2581; fax, 519-973-7062.

Systems, Man and Cybernetics Conference—SMC (SMC); Oct. 17–20; Palais de l'Europe and Westminster Hotel, Le Touquet, France; M.G. Singh, Computation Department, UMIST, Sackville Street, Manchester M60 1QD, England; (44+61) 200 3347; fax, (44+61) 200 3346.

Workshop on Applications of Signal Processing to Audio and Acoustics (SP); Oct. 17–20; Mohonk Mountain House, New Paltz, NY; Harinath Garudadi, INRS Telecom, 16 Place du Commerce, Verdun, PQ H3E 1H6, Canada; 514-765-7729.

International Test Conference—ITC (C, Philadelphia Section); Oct. 17–21; Baltimore Convention Center, MD; Doris Thomas, International Test Conference, 514 E. Pleasant Valley Blvd., Suite 3, Altoona, PA 16602; 814-941-4666; fax, 814-941-4668.

Joint Power Generation Conference—JPGC '93 (PE); Oct. 17–21; Westin Crown Center, Kansas City, MO; J.S. Edmonds, MCM Enterprise Ltd., 2755 Northup Way, Bellevue, WA 98004-1495; 206-827-0460.

International Workshop on Applications of Neural Networks to Telecommunications (COM); Oct. 18–20; Nassau Inn, Princeton, NJ; Betty Greer, Iwannt '93, Bellcore, MRE 2P-295, 445 South St., Morristown, NJ 07960; 201-829-4993; fax, 201-829-5888; e-mail, bg1@failine.bellcore.com.

Oceans '93 (OE, Victoria Chapter); Oct. 18–21; Victoria Conference Centre, Victoria, BC, Canada; Mary O'Rourke, University of Victoria, Box 3030, Victoria, BC V3W 3N6, Canada; 604-721-8470; fax, 604-721-8774.

Advanced Semiconductor Manufacturing Conference and Workshop (ED); Oct. 19–21; Lafayette Hotel, Boston; Margaret Bachmeyer, Semi, 2000 L St., N.W., Suite 200, Washington, DC 20036; 202-457-9584; fax, 202-659-8534.

International Conference on Comput-

Calendar

ers, Communications, and Automation (Region 10, Beijing); Oct. 19–21; 21 Century Hotel, Beijing, China; Zong Sha, Room 2307, 13th Floor, 12 Nongzhanguan Nanlu, Beijing 100026, China; (86+1) 500 1144 3207; fax, (86+1) 500 5233 2307.

International Conference on Network Protocol (C): Oct. 19–22; ANA Hotel, San Francisco; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; 202-728-0884.

Electrical Performance of Electronic Packaging (CHMT, MTT); Oct. 20–22; Hyatt Regency Monterey, CA; Paul A. Baltes, Engineering Professional Development, University of Arizona, Box 9, Harvill Building, Room 235, Second and Olive Streets, Tucson, AZ 85721; 602-621-3054 or 5104; fax, 602-621-1443.

Second International Conference on Document Analysis and Recognition—Icdar '93 (C); Oct. 20–22; Tsukuba Dai-ichi Hotel, Ibaraki, Japan; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Workshop on VLSI Signal Processing (SP et al.); Oct. 20–22; Conference Centre "Koningshoe" Veldhoven, the Netherlands; Ludwig Eggermont, Philips International, B.V./C DC, Groenewoudseweg 1, 5600 MD Eindhoven, the Netherlands; (31+40) 78 49 61; fax, (31+40) 78 64 22; e-mail, eggermont@cpdc.philips.nl.

Active Matrix Liquid Crystal Displays Symposium (ED); Oct. 21–22; Lehigh University, Bethlehem, PA; Austin R. Blew, Lehighton Electronics, Box 328, Lehighton, PA 18235; 215-377-5990; fax, 215-377-6820.

International Symposium on Technology and Society—Istas '93 (SIT, NCAC); Oct. 22–23; George Washington University, Washington, DC; William J. Kelly, 320 N. Edison St., Arlington, VA 22203; 703-883-5745.

International Integrated Reliability Workshop (ED); Oct. 24–27; Stanford Sierra Hotel, South Lake Tahoe, CA; Harry Schafft, National Institute of Standards and Technology, Building 225, Room B360, Route 270, Quince Orchard Road, Gaithersburg, MD 20899; 301-975-2234; fax, 301-948-4081.

International Conference on Application Specific Array Processors—ASAP '93 (C); Oct. 25–27; Ramada Hotel, Venice, Italy; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Second International Workshop on Intelligent Signal Processing and Communication Systems—Ispacs '93 (COM et al.); Oct. 27–29; Aoba Memorial Hall, Tohoku University, Sendai, Japan; Masayuki Kawamata, Department of Electrical Engineering, Tohoku University, Aoba, Aramaki, Aoba-ku, Sendai 980 Japan; (81+22) 263 9411; fax, (81+22) 263 9411.

15th International Conference of the IEEE Engineering in Medicine and Biology Society (EMB); Oct. 28–31; Sheraton Harbor Island Hotel, San Diego, CA; Susan Blanchard, IEEE/Engineering in Medicine and Biology Society, Box 2477, Durham, NC 27715; 919-493-3225.

Ultrasonics Symposium (UFFC); Oct. 31–Nov. 3; Hyatt Regency Hotel, Baltimore, MD; Harry L. Salvo Jr., Westinghouse ESG, 333 Gordon Ave., Severna Park, MD 21146; 410-765-4290; fax, 410-765-7370.

NOVEMBER

International Conference on Silicon Carbide and Related Materials (ED); Nov. 1–3; Omni Shoreham Hotel, Washington, DC; Gary Harris, Materials Science Research Center, Howard University, 2300 6th St., N.W., Washington, DC 20059; 202-806-6618; fax, 202-806-5367.

27th Asilomar Conference on Signals, Systems, and Computers (SP, C); Nov. 1–3; Asilomar Hotel and Conference Grounds, Pacific Grove, California; Rabinder N. Madan, Office of Naval Research, Code 1114, 800 North Quincy St., Arlington, VA 22217-5000; 703-696-4217; fax, 703-696-2611.

Fourth International Symposium on the Physical and Failure Analysis of Integrated Circuits (Singapore Section); Nov. 1–5; Raffles City Convention Centre (Westin Hotels), Singapore; IPFA '93 Secretariat, IEEE Singapore Section, Box 1066, Kent Ridge Post Office, Singapore 9111.

Nuclear Science Symposium—NSS '93 (NPS); Nov. 2–5; Sheraton Palace, San Francisco; Edward J. Lampo, Lawrence Berkeley Laboratory, 1 Cyclotron Rd., 29/100, Berkeley, CA 94720; 510-486-6779; fax, 510-486-4122.

First ACM Conference on Communications and Computer Security (COM); Nov. 3–6; Holiday Inn, Fairfax, VA; Ray Pyle, Bell Atlantic, 11720 Beltsville Dr., 7th Floor, Beltsville, MD 20705; 301-595-7250.

The engineer at large

Money goes to 100 schools for manufacturing studies

A foundation set up by the Society of Manufacturing Engineers (SME), Dearborn, MI, recently awarded US $11.3 million in grants, equipment, and software to 102 universities and technical institutions in the United States. The awards for 1993 almost tripled the $4.1 million in gifts provided last year by SME, which is dedicated to advancing scientific knowledge in the field of manufacturing engineering and management.

The Manufacturing Engineering Education Foundation offers financial incentives to undergraduate programs to spur developments in manufacturing technology and productivity, and to promote manufacturing engineering as an educational discipline, noted foundation president Frank J. Riley. "With the recent emphasis on training a better skilled manufacturing workforce, these programs are essential to future competitiveness," he said.

The bulk of the $10.8 million in gifts went for tools, including computer-aided design and manufacturing software, milling machines, lathes, and robots. Proposal applications for 1994 funding will be available in October from the SME Foundation office. Contact Dora Murray, grants coordinator, 313-271-1500, ext. 512. Founded in 1932, the SME has more than 75 000 members in 68 countries.

Environmental octet

Seeking to bolster public understanding of their role in shaping the environment, eight major national professional design organizations have joined in a Partnership for Sustainable Development.

In announcing the agreement, Joe Paul Jones, president of the National Society of Professional Engineers (NSPE), Alexandria, VA, said that the organizations recognize their obligation to "translate the concepts of science and the dreams of humanity into action through the creative application of planning, design, and technology in order to achieve sustainable development." And Jones continued: "To achieve this vision, we must forge a multidisciplinary partnership to provide expertise and leadership in using and conserving the world's natural resources."

In addition to NSPE, other organizations in the partnership include the American Consulting Engineers Council, American Institute of Architects, American Planning Association, American Society of Civil Engineers, American Society of Consulting Planners, American Society of Landscape Architects, and ASF/Professional Firms Practicing in Geosciences.

Median U.S. engineer salaries up 4.1%

The 1993 Income and Salary Survey released by the National Society of Professional Engineers showed that the income of experienced engineers is barely outpacing inflation. NSPE members responding to the survey reported a median income amounting to US $60 800, a 4.1 percent increase over last year. The median raise reported by those who were not promoted or did not change jobs was 4.7 percent, while the Consumer Price Index rose only 3.3 percent.

The New Jersey counties of Middlesex, Somerset, and Hunterdon showed the highest median income of the 50 metropolitan areas surveyed—$80 000. This represents a $10 000 increase over last year's income in the same region. Lowest incomes were reported in the vicinity of Cleveland, Akron, and Lorain, OH, at $53 475—a 4.5 percent drop from last year.

Petroleum engineers topped the list at $72 500, a 4.3 percent increase, and nuclear engineers came in a close second at $71 468, 10 percent higher than last year. Those in environmental engineering, considered by many to be a "hot field," were solidly in the middle with a median of $61 000, just 3.4 percent above last year.

At the bottom of the list were agricultural engineering and manufacturing engineering. But manufacturing engineers made a sizeable 11.2 percent gain, rising to $56 940. Entry-level engineers saw a 1.4 percent drop in salary to $34 000.

Copies of the NSPE 1993 Income and Salary Survey (Product #0093) are available at $45 (members), $110 (nonmembers) from NSPE Customer Service, 1420 King St., Alexandria, VA 22314; 703-684-2810. A version on disk is also available.

Engineers focus on trade agreement

While the merits of the North American Free Trade Agreement (Nafta) are being debated by politicians and in the press, delegates representing U.S, Canadian, and Mexican engineers have been negotiating matters among themselves. According to the July issue of *Engineering Times*, published by NSPE, the delegates signed two documents in June. One urges Mexico to develop an accreditation system for its engineering education programs, and the other is a "memorandum of understanding" outlining the responsibilities of the delegates, who collectively call themselves the Nafta Forum on Engineering Registration and Practice.

According to the memorandum, the delegates will try to develop recommendations for temporary licensing procedures within two years of Nafta's enactment. Upcoming meetings are being held in Canada in September and in Mexico in January.

Maxwell birthplace acquired

The birthplace of James Clerk Maxwell, located in Edinburgh, Scotland, has been acquired by the James Clerk Maxwell Foundation of Scotland and the United States. In addition to his acknowledged eminence in fundamental science, Maxwell's work has had a profound influence on present-day physics and engineering. He established the electromagnetic nature of light—extending from the visible into the infrared. After his death, the framework he proposed was able to accommodate the discoveries of Herzian (radio) waves, X rays, and gamma rays.

The James Clerk Maxwell Foundation was founded in Scotland in 1975 by a group of scientists and engineers, educators, corporate executives, and bankers who sought to promote and encourage education in science and technology. Maxwell's name was to serve as a reminder of the achievements of a great intellect of the past. The foundation provides research grants to scientists in academia, funds for travel to scientific conferences and for the publication of scientific books, and awards to secondary school students for excellence in science.

Maxwell's home at 14 India St. in Edinburgh's New Town, where he was born in 1831, is to become a center for scholarship, meetings, seminars, and symposia. The Georgian-style house will also display items of interest from Maxwell's life and times, including portraits, letters, and books related to Maxwell, his family, and his scientific contemporaries. Some US $350 000 is needed by year-end to modify and maintain the building for public use, and the foundation has begun a new drive to raise $5 million for its educational programs.

The James Clerk Maxwell Foundation of the United States is a tax-exempt charitable organization. It is located at 4109 Great Oak Rd., Rockville, MD 20853; 301-929-9516; fax, 301-929-1636. In Scotland, contact 11 Ann St., Edinburgh EH4 1PL, Scotland; (44+31) 332 1455; fax, (44+31) 343 3166.

COORDINATOR: Alfred Rosenblatt

EEs' tools & toys

Early support on the way for Pentium processor

With the ink barely dry from the announcements in the press of Intel's Pentium microprocessor, design support hardware for the new chip is already available from at least

Microtek's in-circuit emulator for the Pentium microprocessor operates nonintrusively by running at the chip's full speed of 66 MHz.

two instrument suppliers. Microtek International has introduced an in-circuit emulator for the new processor, and Tektronix has announced that two of its logic analyzers, the GPX and the DAS 9200, now support it. The speedy availability of the support products is the result of a new Intel policy of cooperating with vendors of development tools—a policy that the company regards as essential in a world where products get superseded in 18 or fewer months, and every day lost in introducing a new product means millions of dollars in lost revenue.

In addition to bringing the support instruments to market quickly, Intel's cooperation also made them extremely competent. In the case of the Microtek Pentium Emulator (MPE), that translates into the ability to run at the Pentium's full clock speed of 66 MHz and to capture accurate execution histories, even when the processor is executing code out of cache. Other key MPE features include eight complex bus-event recognizers; a 32-bit occurrence counter; time stamping (with 15-ns resolution) on every bus cycle; and four debug registers for execution, memory access, memory write, or I/O access breaks.

The MPE runs under the control of an IBM PC. Minimum host requirements are a 33-MHz 386 microprocessor, DOS version 5.0, Microsoft Windows 3.1, 4 megabytes of RAM (8M bytes recommended), a VGA color monitor, 10M bytes of hard disk space, and a serial (COM) port. The emulator sells for US $47 995, and is available now.

Tektronix' support takes the form of a probe adapter and full disassembly capability for its GPX logic analyzer and its DAS 9200 systems analysis platform. With the adapter, the instruments support the Pentium at its full 66-MHz clock rate and provide 10-ns triggering. Both analyzers offer comprehensive performance analysis capability, including the identification and labeling of nonexecuted instructions—even with speculative prefetching.

Pentium support for the GPX costs $4000; the DAS version is priced at $6000. Until Nov. 26, it is being offered free of charge to purchasers of new two-module GPX systems and to purchasers of certain DAS upgrades. *Contacts: Microtek International, Development Systems Division, 3300 N.W. 211th Terrace, Hillsboro, OR 97124; 800-886-7333; fax, 503-629-8460; or* **circle 102;** *and Tektronix Inc., Test and Measurement Group, Box 1520, Pittsfield, MA 01202; 800-426-2200; fax, 503-690-3959; or* **circle 103.**

GENERAL INTEREST

The charm of calculators

Remember the Bowmar Brain, the Craig Mark II, and the Hewlett-Packard HP-35? If so, you are not alone. A couple of wild and crazy guys in California (where else?) are so interested in collecting electronic calculators and preserving their history that they have founded the International Association of Calculator Collectors and have begun publishing a newsletter, *The International Calculator Collector.*

The first issue is already on the streets, and it certainly does credit to its founders, Guy Ball, an electronics engineer, and Bruce Flamm, a physician. Its eight pages include historical articles; a reproduction of an early ad; a profile of the defunct Bowmar company; answers to the question "Why collect old calculators?"; and even half a page of classified ads, which are free to members.

Association membership, which includes a subscription to the newsletter, costs US $8 per year ($12 for overseas mailing). A sample issue of the newsletter is offered for two 29-cent U.S. postage stamps. *Contact: Wilson/Barnett Publishing, 1212 So. Parton St., Santa Ana, CA 92707; or* **circle 104.**

INSTRUMENTATION

15-MHz multifunction generator

In an effort to combat the perception that its initials stand for "High Price," Hewlett-Packard has, for a couple of years now, been putting together a line of basic bench instruments whose costs are held down by a combination of clever manufacturing techniques and the elimination of less important features and cutting-edge specifications. The latest product in the line is the Model 33120A, a 15-MHz function and arbitrary-waveform generator.

Other than its moderate top frequency and spectral purity, the US $1695 generator differs little from units costing three times as much. Its standard repertoire of waveforms includes sine and square waves from 100 μHz to 15 MHz; triangles and ramps from 100 μHz to 100 kHz; bandlimited (10 MHz) noise; $\sin(x)/x$, exponential rise, and exponential fall waves up to 5 MHz; a simulated electrocardiogram output; and dc. Also built in are AM, FM, frequency-shift keying (FSK), burst, and sweep modulation capabilities. The unit will sweep in either direction, linearly or logarithmically, as fast as once a millisecond or as slowly as once every 500 seconds.

The generator is a direct synthesized unit—that is, its analog output is created by clocking a series of digitally computed values into a digital-to-analog converter

Priced at only US $1695, the Hewlett-Packard 33120A function and arbitrary-waveform generator is a direct synthesized 15-MHz instrument with a host of built-in waveshapes and modulation capabilities.

and then passing the converter's output through a filter and an output amplifier. The maximum clocking rate into the 12-bit d-a converter is 40 megasamples per second. Because of that rate limitation (and limitations in the output amplifier), sine wave harmonic distortion, which is a full 70 dB down up to 20 kHz, is only 35 dB down from 1 MHz to 15 MHz. Similarly, nonharmonic distortion, which is 65 dB below the signal up to 1 MHz, rises 6 dB per octave from 1 MHz to 15 MHz.

As an arbitrary-waveform generator, the 33120A produces waveshapes defined by 8 to 16 000 points. These arbitrary waveforms can have maximum repetition frequencies from 200 kHz to 5 MHz, depending on how many points they contain. The generator can store four 16 000-point or eight 8000-point waveforms in its nonvolatile memory.

The generator's peak-to-peak output amplitude can be varied from 50 mV to 10 V into 50 Ω. Sinewave flatness is within 0.1 dB up to 100 kHz and 0.2 dB up to 15 MHz. Maximum offset (into 50 Ω) is 5 V peak ac plus dc. *Contact: Hewlett-Packard Co., Direct Marketing Organization, Box 58059, MS51L-SJ, Santa Clara, CA 95051-8059; 800-452-4844; or* **circle 106.**

Emulating the 68360 already

Reckoning that Motorola's recently announced 68360 quad integrated communications controller (Quicc) may well have as many as 200 design wins by the first quarter of next year, Applied Microsystems Corp. made a commitment to provide timely support for the chip—and did indeed follow through on it this month with news of a full-scale emulator for the Quicc. That emulator, the EL 3200 for the 68360, runs in-target at full speed and boasts such advanced features as Ethernet connectivity, intelligent trace disassembly, and real-time pin tracking.

The Ethernet connectivity enables a number of engineers to share a single emulator while each works at his or her own workstation. Intelligent trace disassembly tracks dynamic variables without stopping emulation, thus improving both the efficiency and accuracy of the debugging process. Real-time pin tracking also adds to efficiency by letting users see address pins that have been reprogrammed.

The emulator supports both the 68360 and the 68EN360 (Ethernet) versions of the chip. It offers complete electrical and logical isolation, employing FET switches to get subnanosecond switching at its pins.

Additional debugging features include a complex event system that allows up to eight event statements for each of four event groups—of help in searching for deeply nested bugs. The emulator provides 16 hardware access breakpoints, 16 hardware execution breakpoints, and 1024 software execution breakpoints.

The EL3200 for the 68360 is priced at approximately US $25 000 and has a delivery time of four to six weeks. Those who own a chassis for the 68330/340 can upgrade to the 68360 for about $14 000. *Contact: Applied Microsystems Corp., Box 97002, Redmond, WA 98073-9702; 206-882-2000; toll-free, 800-426-3925; fax, 206-883-3049; or* **circle 107.**

Measuring magnetic properties

Transformer designers, makers of lamp ballasts, engineers working on high-definition TV, and other makers and users of soft magnetic materials can benefit from the Walker AMH-400 Computerized Hysteresisgraph. The unit measures the ac magnetic properties of electrical steels and soft ferrites at frequencies from 50 Hz to 1 MHz.

It can run a hysteresis loop, calculate the parameters, and display the results—both curves and data—on a high-resolution color monitor, all within 30 seconds. The Hysteresisgraph is accurate to within 2 percent for B (magnetic induction) and H (magnetizing force) values, and 5 percent for core loss. Measured parameters include remanence (B_r), coercivity (H_c), B_{max}, H_{max}, peak permeability (μ_p), peak secondary voltage, and phase lag between the secondary voltage and the exciting current.

The PC/AT-based measuring system lets users define more than 1000 test setups, set pass/fail limits for all parameters, store up to 1000 test results, and make hard copies of test results on standard printers and plotters. *Contact: Walker Scientific Inc., Rockdale St., Worcester, MA 01606; 508-852-3674; toll-free, 800-962-4638; fax, 508-856-9931; or* **circle 108.**

AUTOMATION

Control conference proceedings

Control engineers who could not make it to the 1993 American Control Conference this past June may be interested to learn that leftover copies of the conference proceedings are now available through the IEEE. The three-volume set includes more than 700 papers and runs to some 3200 pages.

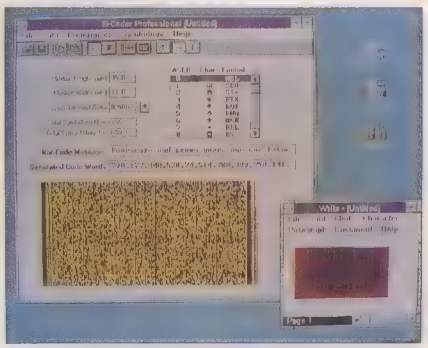
Among the subjects covered are: robotics, manufacturing, guidance and flight control, power systems, process control, measurement and sensing, identification and estimation, signal processing, modeling and advanced simulation, model validation, multivariable control, adaptive control, robustness issues, intelligent control, expert systems, industrial applications, and control education.

The proceedings are priced at US $142 for members of the IEEE and some other engineering societies. The nonmember price is $284. The catalog number is 93CH3225-0. *Contact: IEEE Service Center, Box 1331, Piscataway, NJ 08855-1331; 908-981-0060; 800-678-4333; fax, 908-981-9667; or* **circle 105.**

SOFTWARE

Bar codes for Windows

B-Coder Professional is an easy-to-use program that generates bar codes and places them in the Windows clipboard, whence they may be pasted directly into files or documents created with other Windows programs and printed on any standard printer. Thus it becomes simple to generate barcode labels for items in a database or spreadsheet, or to annotate documents like invoices and laboratory reports with bar codes.



B-Coder Professional is a Windows-based bar-code generator that supports all standard bar-code symbologies, including the two-dimensional PDF417. Shown here (in yellow) is a portion of Lincoln's Gettysburg Address.

The program generates high-quality bar codes of all symbologies and sizes, including the two-dimensional PDF417 format, which can encode more than a thousand characters in a single bar code [see photo].

B-Coder Professional sells for US $199. *Contact: T.A.L. Enterprises, 2022 Wallace St., Philadelphia, PA 19130; 215-763-2620; toll-free, 800-722-6004; fax, 215-763-9711; or* **circle 109.**

A pride of programs

"Software For Science" is a 64-page catalog of scientific and technical software for DOS, Windows, Macintosh, and Unix workstation platforms. It has descriptions of more than 600 products, along with a series of brief notes and tips on buying and using them.

In addition to the 600-plus products listed in the catalog, SciTech International, its publisher, maintains a database of more than 3000 software tools. So readers who cannot find what they need in the catalog may contact the company for additional help.

The catalog is offered free of charge. *Contact: SciTech International Inc.,*

Tools & toys

Bailiwick Court Bldg., 2231 N. Clybourne Ave., Chicago, IL 60614-3011; 312-472-0444; fax, 312-472-0472; or **circle 110.**

EDUCATION

Learning about fuzzy logic

To help students and potential users of the technology learn what fuzzy logic is, how it works, and what it can do for them, HyperLogic Corp. has introduced CubiQuick, a scaled-down version of its popular CubiCalc fuzzy logic shell. Prices of US $179, with an academic price of $125, and even lower pricing for classroom use, should eliminate cost as a barrier to familiarity with fuzzy logic.

CubiQuick lets users define fuzzy rules with up to three input variables and a single output variable. Up to five fuzzy sets may be used to describe each variable. A built-in computation language preprocesses data taken from external files or simulates external responses to fuzzy control actions.

Results from the rules and from user-defined non-fuzzy computations can be plotted or displayed numerically. As HyperLogic president Fred Watkins put it, "You can solve real problems with CubiQuick, just not very big ones." *Contact: HyperLogic Corp., 1855 East Valley Parkway, Suite 210, Escondido, CA 92027; 619-746-2765; fax, 619-746-4089; or* **circle 111.**

DIGITAL SIGNAL PROCESSING

Sparcstation support for the Hydra

It is difficult to debug a multiprocessor board with a PC-based debugger. That's the trouble with developing applications for Ariel Corp.'s VMEbus-based Hydra DSP board. For that (and other) reasons, ESI Computing Inc. has created HydraLink—an attached VMEbus array processor and real-time signal-processing system based on a Sun Sparcstation and the Hydra board. (The Hydra is a DSP board based on multiple Texas Instruments TMS320C40 digital signal processors, and capable of 200 million floating-point operations per second.) Besides its usefulness for developing embedded Hydra-based systems, HydraLink can be used as a target system for applications such as data acquisition, in which the Sparcstation is part of the final system.

HydraLink consists of a five or 12-slot card cage, one or more Hydra boards, an SBus-to-VMEbus adapter, and SunOS device drivers. Also available for HydraLink are Ariel's AXDS-Sun multiprocessor source-level debugger; Ariel's hand-optimized C-callable DSP expert library; the MathWorks' Matlab, Simulink, and Matlab Signal Processing ToolBox; Texas Instruments' ANSI-compatible C cross compiler; and Spectron's SPOX real-time operating system, which resides on the Hydra board, and the company's development tools, which reside in the Sparcstation.

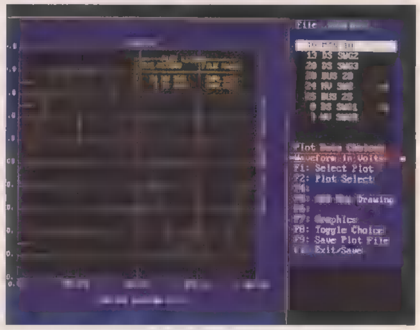
One of the great advantages of HydraLink is that it is a thoughtfully integrated system, all of whose components work well with each other. Moreover, the system is fully supported by ESI.

A HydraLink with a 12-slot card cage, a 400-W power supply, an SBus-to-VMEbus adapter, fans, peripheral bays, and drivers costs US $12 490. Matlab adds $3995 to that price; the DSP expert library adds $1495; and SPOX adds from $2000 to $12 000, depending on configuration. Hydras start at about $10 000 for a two-processor board. *Contact: ESI Computing Inc., 468 Westford Rd., Carlisle, MA 01741; 508-369-8499; fax, 508-369-7612; or* **circle 112.**

POWER AND ENERGY

Investigating harmonics

The best time to deal with problems is before they occur. With Hi_Wave, a PC-based harmonic investigation and analysis program from SKM Systems Analysis Inc., power engineers can now do just that—examine new power systems before they are built and address negative harmonic effects during design. The program is also good at analyzing extant power systems and developing specifications for corrective filters.



Hi_Wave is a harmonic analysis software package for power systems. This display of a voltage waveform is just one of its ways of presenting harmonic distortion data.

Hi_Wave uses sparse-matrix and current-injection methods to model harmonic voltage and current distortion quickly and accurately. The program also performs frequency scans for all system resonance points; calculates nonlinear frequency-dependent characteristics for feeders, transmission lines, and transformers; and analyzes harmonic load flow.

Computer requirements for the program are modest: it needs a 286-based PC with 640K bytes of RAM, MS-DOS 3.3, and EGA graphics capabilities. Any modern PC easily

Tools & toys

exceeds all these requirements. Users with a 386-based PC and 2M bytes of RAM may prefer Hi_Wave/386, which knocks about 30 percent off execution time for large projects. The program is offered in 100-, 300-, and 1000-node versions, priced at US $3950, $4150, and $4650, respectively. *Contact: SKM Systems Analysis Inc., 225 South Sepulveda Blvd., Suite 350, Manhattan Beach, CA 90266; 800-232-6789; fax, 310-372-2171; or* **circle 113.**

DATA ACQUISITION

Behind open Windows

When used with the company's WinDaq playback and analysis packages, Dataq's new WinDaq/200 multitasking data-acquisition software allows users to acquire, review, store, and analyze waveforms—all within the Microsoft Windows environment. Perhaps more importantly, it permits data to be acquired and stored on a PC's hard disk in the background while another Windows application is running in the foreground.

WinDaq/200 can acquire data from as many as 16 channels at rates as high as 83 000 samples per second. It makes it easy for users to reconfigure their systems, changing the number of acquisition channels and their positions on the computer screen. The program provides a choice of smooth scrolling, freeze, auto-sweep, or triggered display modes.

WinDaq/200 lists for US $595. *Contact: Dataq Instruments Inc., 150 Springside Dr., Suite B220, Akron, OH 44333-2473; 800-553-9006; or* **circle 114.**

Linear products catalog

Burr-Brown has updated the disk containing its linear products catalog. For IBM PC and compatible computers, the *High performance electronics selection guide* has data on more than 1500 components, industry cross-references, technical literature, U.S. prices, and ordering information.

Product categories include analog circuit functions, converters, isolation and operational amplifiers, and multiplers. The disk also contains an updated PSpice macromodel library with 103 of the company's newest models.

The selection guide is available free of charge from any Burr-Brown sales office or representative, or by calling 1-800-548-6132. *Contact: Richard Kulavik, applications engineer, Burr-Brown Corp., Box 11400, Tucson, AZ 85734; or* **circle 115.**

COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

CLASSIFIED EMPLOYMENT OPPORTUNITIES

The following listings of interest to IEEE members have been placed by educational, goverment, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

ADVERTISING RATES

Positions open—$36.00 per line, not agency-commissionable

Positions wanted—$36.00 per line, a 50% discount for IEEE members who supply their membership numbers with advertising copy.

All classified advertising copy must be received by the 25th of the month, two months preceding the date of issue. No telephone orders accepted. For further information call 212-705-7578.

IEEE encourages employers to offer salaries that are competitive, but occasionally a saslary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

Academic Positions Open

Grad Student Ph.D. Assistantships open for only highly experienced engineers in the power quality area. Send resume with refs and GRE to Dr. Alex Domijan, Director, Florida Power Affiliates, Dept. of Electrical Engineering, Univ. of Florida, 323 Benton Hall, Gainesville, FL 32611, (904)392-0290.

Postdoctoral Scientific Research Opportunities in India. 3-12 month fellowships in India awarded to U.S. citizens. For information, contact: Jeanine Marie Greene, Academy for Educational Development, 1255 23rd Street, NW, Washington, D.C. 20037.

Faculty Position in Electrical Engineering, California Institute of Technology. The Electrical Engineering Department at Caltech invites applications for tenure-track positions as Assistant Professor. The term of the initial appointment is normally four years and is contingent upon completion of PhD. Exceptionally qualified senior applicants may also be considered. We are especially interested in applicants from the area of Electrical Systems, i.e., Communications, Control, and Signal Processing. We are seeking highly qualified candidates who are committed to a career in research and teaching. Applicants should submit a resume, a one-page statement of research accomplishments and plans, three letters of recommendation, and up to five of their most significant conference or journal publications to: Professor R.J. McEliece, Chairman, EE Search Committee, Department of Electrical Engineering (116-81), California Institute of Technology, Pasadena, CA 91125. Caltech is an Equal Opportunity/Affirmative Action Employer. Women and minorities are encouraged to apply.

Professorships. The Toyota Technological Institute (TTI), established in 1981 by a donation from the Toyota Motor Corporation, offers undergraduate and master's degree programs. To further strengthen education and research at the graduate level, TTI is adding a doctoral program which will focus on the following disciplines; Information Aided Technology, including Advanced Information Theory, Information Processing, Information/Motion Transformation Theory, Thermofluid Dynamics, Intelligent Design, and Information Integrated Realization Technology. Future Industry-oriented Basic Science and Materials including Ultimate Structure & Properties, Molecular Design; Characterization & Properties, Noble Crystals & Semiconductors, Structure-Controlled Materials, Singular Layers in Materials, and Beam Processing. To commence this ambitious effort, TTI is currently seeking 5-8 senior faculty members at the full professor level to join this distinguished community by April 1, 1995. Selected individuals will organize a unit laboratory, which consist of 1 professor, 1 associate professor, 2-3 post doctoral research associates and students. Support for research start-up expenses and an annual research budget will be provided, in addition to a salary and fringe benefit package. Details will be provided upon inquiry. Qualified applicants are invited to send their curriculum vitae, a statement of research interests and ■ list of publications, by Oct. 30, 1993, to: Dr. M. Nagasawa, Vice President, Toyota Technological Institute, 2-12-1 Hisakata, Tenpaku-ku, Nagoya, Aichi 468, Japan. You may also inquire by Fax to Japan 81-52-802-6069. An Equal Opportunity Employer.

Department of Electrical and Computer Engineering, Northeastern University in Boston seeks tenure track faculty, at all professional levels, in the areas of (1) Computer Engineering (computer architecture), software engineering, VLSI systems design for test and fault tolerance, (2) telecommunication networks, (3) digital signal processing and (4) microelectronics. The ECE Department currently has forty-seven full-time faculty, two nationally and internationally recognized research centers, a large and expanding graduate program, and sponsored research exceeding five million dollars annually. Expansive opportunities for research exist due to one of the highest concentrations of high technology in the nation. Ph.D. in Electrical Engineering, Computer Engineering, Computer Science or related field required with previous academic or industrial experience preferred. Salary and rank are commensurate with experience. Send resumes to: John G. Proakis, Chairman, Electrical and Computer Engineering, 309 Dana Research Building, Northeastern University, 360 Huntington Avenue, Boston, MA 02115. Northeastern is an Equal Opportunity/Affirmative Action, Title IX Employer.

Postdoc in Electric machines, drives and power electronics. The University of New Orleans envisages a vacancy in the near future to work on an EPRI/Energy grant. Please send resume with the names and phone numbers of 3 referees to: Dr. P. Pillay, Dept. of Elec. Eng., UNO, LA 70148. UNO is an EOE.

Visiting professor in Electrical Engineering and Computer Science, US Military Academy. Applications are invited for AY-1994-1995 for appointment consideration under the provisions of the intergovernmental personnel act of 1979. Applicants must have Ph.D., possess a strong commitment to undergraduate teaching, and currently hold the academic appointment of professor or associate professor. Duties include teaching in, and providing advice on, the academy's electrical engineering and computer science programs. Compensation is usually commensurate with that currently being received. Send resumes to Colonel Lanse M. Leach, Department of Electrical Engineering and Computer Science, US Military Academy, West Point, NY 10996. Applications must be received by 15 October 1993. The US Military Academy is an affirmative action/equal opportunity employer.

The University of Cincinnati Electrical and Computer Engineering Department. Applications are solicited for tenure track Assistant/Associate Professor faculty positions in the Department of Electrical and Computer Engineering starting January/September, 1994. Applicants in the following areas are of special interest: (1) Computer System Design, including programming languages, compiler design, networks, software engineering, parallel and distributed computing, operating systems, databases, architecture, computation theory, and VLSI systems design, test, verification, and VLSI CAD tool development; (2) Intelligent Systems and Informatics, including computer vision, artificial neural network-based systems, manufacturing and discrete-event systems, automatic factory control, intelligent control systems, and micro-electromechanical systems, including micro-sensors, micro-machining, and integrated circuit design for smart sensing; (3) Microwave and millimeter wave devices, circuits, and systems, and photonic and optoelectronic devices, circuits and systems. The Department offers MS/Ph.D. programs in electrical engineering, computer engineering, and computing sciences as well as an ABET fully-accredited undergraduate program in Electrical and Computer Engineering. The Department has 30 full-time faculty, 200 full-time graduate students, 400 undergraduate students and graduates 35 M.S. and 15 Ph.D.s per year. The Department is very well equipped in both teaching and research labs with state-of-the-art networked computing facilities. The University is supportive of the Department in providing an environment conducive to the establishment of an academic and professional career. All candidates should have an earned Ph.D. in Electrical Engineering, Computer Engineering or Computer Science. Please send curriculum vitae and the names of three references to: Prof. Vik J. Kapoor, Head, Electrical and Computer Engineering Department, Mail Location 30, University of Cincinnati, Cincinnati, Ohio 45221-0030 (e-mail vkapoor@uceng.uc.edu). The University of Cincinnati is an Affirmative Action/Equal Opportunity employer and encourages and welcomes applications from women and minorities.

Wayne State University anticipates openings for tenure-track faculty in the Electrical and Computer Engineering Department. We are seeking research oriented individuals in (i) computer engineering, with emphasis on any of the following: networks, parallel and distributed systems, high performance computing or VLSI design, and (ii) photonic devices and systems with emphasis on any of the following: nonlinear optics, optical sensors, quantum interference, or multi-spectral processing. Applicants should have an earned Ph.D. and be committed to teaching and research. Rank and salary will depend on experience and qualifications. Wayne State is a large urban university, and welcomes applications from women and minorities. Send resumes to Dr. A.W. Olbrot, Search Committee Chair, ECE Dept., Wayne State University, Detroit, MI 48202. Wayne State University is an Equal Opportunity/Affirmative Action employer. Wayne State University - People working together to provide quality service.

Cooper Union. Tenure track assistant professor, Electrical Engineering. Duties include teaching undergraduate electronics, directing undergraduate electronics, projects, and supervising master's theses candidates. Research is encouraged through the Cooper Union Research Foundation. Only candidates with a strong interest in laboratory development should apply. Ph.D. required . Please contact Dr. Melvin Sandler, The Cooper Union, 51 Astor Place, N.Y., N.Y. 10003. Cooper Union is an equal opportunity affirmative action employer.

Dean, Thayer School of Engineering. Dartmouth College. Applicants should have a doctoral degree and be eligible for ■ tenured full professorship in engineering. Apply to Professor Graham B. Wallis, Chair, Thayer School Dean Search Committee, 6004 Parkhurst Hall, Room 204, Dartmouth College, Hanover, NH 03755-3529. Review of applications begins October 1, 1993 for appointment July 1, 1994. Dartmouth College is an AA/EO Employer.

West Virginia University. The Department of Electrical and Computer Engineering at West Virginia University anticipates possible faculty positions in the area of signal processing, communications, and control, and the area of electronics, opto-electronics, and computers. Salary and rank will be commensurate with qualifications. Positions will be tenure track. Applicants must have the Ph.D., must have potential for high quality teaching, and will be expected to initiate research and participate in departmental research programs. A curriculum vitae and cover letter identifying an area of specialization should be sent to: Faculty Search Committee, Department of Electrical and Computer Engineering,

West Virginia University, P.O. Box 6101, Morgantown, WV 26506-6101. Applications will be received and considered immediately and searches will continue until all available positions are filled. West Virginia University is an affirmative action/equal opportunity employer.

The Department of Electrical Engineering, North Carolina Agricultural and Technical State University, invites applications for tenure-track faculty positions at all ranks in the specific areas of computer engineering, microprocessors and control systems, and solid state materials and devices. Applicants must have a Ph.D. in electrical or computer engineering with demonstrated teaching and research accomplishments or potential. Academic duties include teaching and developing undergraduate and graduate courses, and initiating and conducting sponsored research in areas relevant to the Department. The Department offers the BSEE and MSEE degrees, and is in the process of establishing a Ph.D. degree program. The majority of the current 19-member faculty are actively engaged in sponsored research in the areas of computer engineering, data communications, photonics, power systems, signal processing, and solid state electronics. North Carolina A&T State University is a constituent institution of the University of North Carolina system, and is a participating member of the Microelectronics Center of North Carolina (MCNC). Initial appointments are for 9 months at a rank and salary commensurate with qualifications. Interested applicants should send a resume with citizenship/visa status clearly indicated and names of three references to: Dr. Ward Collis, Faculty Search Committee, Department of Electrical Engineering, North Carolina A&T State University, Greensboro, NC 27411, no later than October 15, 1993. North Carolina A&T State University is an affirmative action, equal opportunity employer.

Faculty Position in Electrical Engineering - The Faculte des sciences appliquees of the Universite de Sherbrooke, Quebec, Canada, invites applications for a tenure-track faculty position in electrical engineering. General responsibilities - Teaching at undergraduate and graduate levels, specialized research in electrical engineering, graduate students supervision and training, course and program management and community involvement. General qualifications - Ph.D. in electrical engineering; excellent communication skill, strong commitment to teaching, research and technology transfer; excellent knowledge of written and spoken French; qualifications to become member of the Ordre des ingenieurs du Quebec. Specific qualifications - Specialization in the design of analog and digital electronics systems; meaningful design experience of ASIC circuits and gate array technologies. Candidates should send their resume and c.v. before October 4, to: The Dean, 93-1-23, Faculte des sciences appliquees, Universite de Sherbrooke, Sherbrooke, Quebec, Canada J1K 2R1. Salary and working conditions are in accordance with the terms of the current collective agreement. The Universite de Sherbrooke is an equal opportunity employer and encourages applications from qualified women. In accordance with Canadian immigration requirements, this advertisement is directed in the first instance to Canadian citizens and permanent residents of Canada.

New Program in Computer Engineering. Department of Electrical Engineering, South Dakota School of Mines & Technology: Continuation of Faculty Search. Applications are invited for an Assistant or Associate Professor level, tenure track faculty position in the area of Computer Engineering. The school has a new program leading to a B.S. degree in Computer Engineering and the successful candidate will be involved in developing this new program. It is expected that the position will be filled by January 1, 1994, but the search will remain open until the position is filled. Duties will include developing and teaching undergraduate courses in the new Computer Engineering program, teaching undergraduate and graduate courses in the Electrical Engineering program, promoting and developing research, and directing research of graduate students. The areas of interest include all the fields of Computer Engineering, especially those with a hardware oriented emphasis towards either VLSI design, microprocessors or digital systems. Applicants must possess a doctoral degree in Computer or Electrical Engineering, or be scheduled to complete all degree requirements, preferably by January 1, 1994. Salary is commensurate with qualifications and experience. South Dakota School of Mines and Technology, founded in 1885, has an enrollment of approximately 2,500 students and offers degrees in the major branches of engineering and the physical sciences. Applications must include a complete resume, indicating the actual or scheduled date of completion of all degree requirements, a statement of teaching and research interests, and names and addresses of three references. The applications should be sent to: Dr. A. L. Riemenschneider, Department Head, Electrical Engineering Department, South Dakota School of Mines and Technology, 501 East St. Joseph Street, Rapid City, SD 57701-3995, phone (605) 394-2451. Screening of applications will begin on November 1, 1993. South Dakota School of Mines and Technology does not discriminate on the basis of race, color, national origin, sex, religion, age or disability in employment or the provision of service.

The Department of Electrical and Computer Engineering at the University of New Mexico invites applications for a full-time, tenure-track, faculty position at the level of associate professor. Applicants must have a Ph.D. in electrical/computer engineering, or a closely related field. Desirable areas of concentration are neural networks, pattern recognition, and virtual reality. In addition to regular teaching and service responsibilities, the faculty member in this position is expected to build a strong research program in his/her area of specialization. Preference will be given to those individuals with proven leadership abilities in building research programs; some industrial experience is also desirable. Resume and a list of three (3) references must be received by mail, by October 31, 1993. Send to: Prof. Don Hush, Search Committee Chair, Electrical and Computer Engineering Department, The University of New Mexico, Albuquerque, NM 87131. The University of New Mexico is an Equal Opportunity/Affirmative Action Employer.

United States Naval Academy: The Weapons and Systems Engineering Department invites applications for a full time, tenure-track, junior faculty position. The department teaches an ABET accredited major in Systems Engineering. The emphasis is on control systems, with other areas of interest including communications, computers, and robotics. Duties include teaching, course development, and scholarly activity. A doctorate is required in a related field. The Naval Academy is an undergraduate institution dedicated to teaching excellence. Class sizes are moderate and laboratories are generously equipped. Research opportunities are plentiful in nearby naval laboratories. Annapolis is located on the scenic Chesapeake bay, and is equidistant between Baltimore MD and Washington DC. Send resume to Professor Robert DeMoyer, Chairman of W&SE Department, 105 Maryland Ave., Annapolis, MD 21402. The Naval Academy is an equal opportunity/affirmative action employer. Women and minority candidates are actively encouraged to apply.

Faculty Position - Clemson University: The Department of Electrical and Computer Engineering seeks candidates for one or more tenure track positions. Top priority will be given to individuals with a specific interest in the area of control theory and robotic systems. It is anticipated that the successful candidate will have strong interest in computer integration of robotic systems, discrete implementation of low- and high-level algorithms for mechatronics systems, or path planning and redundancy for robotic systems. The successful candidate would likely have some teaching responsibility in embedded systems and interfacing. Candidates should hold the Ph.D. degree in Electrical or Computer Engineering and have a strong interest in teaching at both the undergraduate and graduate levels. Clemson University's College of Engineering was listed as one of the United States' "up-and-coming" engineering graduate programs in the March 19, 1990 issue of the U.S. News and World Report. The ECE Department has 36 full-time faculty, approximately 500 undergraduate students, and 200 graduate students. It offers B.S., M.S., and Ph.D. degrees in both electrical engineering and computer engineering. Facilities include the Center for Advanced Manufacturing, which is shared with other engineering departments and which contains ten robot manipulators, five high-speed computer systems, two mechatronic workstations, and a variety of sensors and computer vision facilities. The Department has strong links with the Department of Energy and is engaged in robotic development for waste storage site inspection and for facilities decontamination and decommissioning. Clemson University is the land-grant university for South Carolina and is located in the state's scenic Piedmont region. The quality of life stems from the outdoor recreation available, the reasonable cost of housing and living, and the thriving metropolitan area of Greenville, approximately thirty miles from campus. Greenville has been ranked recently by Inc. Magazine as one of the twenty fastest growing markets in the country. Interested persons should send a curriculum vitae and the names of at least three references to L. Wilson Pearson, Head, Department of Electrical and Computer Engineering, Clemson University, Clemson, South Carolina 29634-0915. Consideration of candidates will begin on November 1, 1993 and will continue until position(s) is (are) filled. Clemson University is an Equal Opportunity/Affirmative Action Employer.

Postdoctoral Fellow. The Imaging Sciences Division of the Crump Institute for Biological Imaging and the Department of Pharmacology, UCLA School of Medicine, invites applicants for a postdoctoral fellowship with special emphasis on development of instrumentation for imaging small laboratory animals. Candidates should have a Ph.D. in physics, engineering or related field with experience and an interest in PET, SPECT, nuclear electronics or nuclear instrumentation. Familiarity with image reconstruction techniques and computer programming would be beneficial. Salary dependent on experience. Submit curriculum vitae, bibliography and 3 supporting letters to: Simon R. Cherry, Ph.D., Crump Institute for Biological Imaging, Department of Pharmacology, UCLA School of Medicine, Rm. B2-086 CHS, Los Angeles, CA 90024-1721. Equal Opportunity/Affirmative Action Employer.

Deane Ackers Professor of Electrical and Computer Engineering. The University of Kansas, Department of Electrical and Computer Engineering invites applications and nominations for a chaired professor. The Deane Ackers Professor of Electrical Engineering will be expected to teach and conduct sponsored research as a part of the Remote Sensing and Radar Systems Laboratory (RSL) in one or more of the following areas: microwave remote sensing, electromagnetics, microwave engineering, or radar systems. Candidates must have an earned doctorate in electrical engineering, physics, or applied mathematics. He/She must have an outstanding record of research in one or more of the above mentioned disciplines and have an international reputation. The Radar Systems and Remote Sensing Laboratory (RSL) has a long history of graduate education and research. Through RSL, the University of Kansas is internationally recognized for its training and research activities in the fields of microwave remote sensing, radar, and applied remote sensing. In addition to research in remote sensing, the Electrical and Computer Engineering Department has active research programs in telecommunications and information sciences, and computer engineering. The successful candidate will provide leadership in research, teach, and establish significant collaborations with governmental and industrial researchers and engineers. The salary, which will be commensurate with the outstanding qualifications required of the appointee, will be subject to negotiation. Applications and nominations should be sent to Prasad Gogineni, chairman of the search committee, the Electrical and Computer Engineering Department, 1013 Learned Hall, Lawrence, KS 66045. Review of applications will begin on August 15, 1993 and will continue until the position is filled. The University of

ity of a limited number of temporary post doctoral research positions in the general areas of photonics and quantum electronics. Salary will commensurate with the qualifications and experience of the candidate. Preferred areas of interest include (but are not limited to) blue-green and ultraviolet materials and devices; optical communications; atmospheric propagation; development of ultrafast lasers; strong-field science and applications; ultrafast investigations of processes, materials and devices; growth, fabrication, and characterization of traditional and non-traditional photonic materials and devices; and photonics engineering. The search will remain open until all positions are filled. Women and minorities are encouraged to apply. Applicants should send a complete vitae and the names of three references to: Post Doctoral Screening Committee, Center for Laser Science and Engineering, 144 Iowa Advanced Technology Laboratories, University of Iowa, Iowa City, Iowa 52242-1000. (319) 335-3461. The University of Iowa is an Equal Opportunity/Affirmative Action Employer.

Columbia University. The Department of Electrical Engineering invites applicants for several faculty positions. Areas of interest include: (1) Telecommunications including wireless, multimedia, and network management and control; (2) Signal/Image/Video Processing; (3) VLSI Circuits and Systems; (4) Photonics; and (5) Microelectronics. We are interested in experienced persons who can make an immediate impact. The candidate is expected to have an outstanding track record in research and to be experienced in attracting funding. The research will be conducted in conjunction with either the NSF Center for Telecommunications Research or the Microelectronics Sciences Laboratories. Please send resume and the names of three references to: Professor E.S. Yang, Chairman, Department of Electrical Engineering, Columbia University, 500 West 120th Street, Room 1312, New York, NY 10027. Minorities and women are encouraged to apply. Columbia is an equal opportunity/affirmative action employer.

Senior Research Associate. Perform research in architectures for query processing in persistent object bases. Work includes: (1) determination of major software components and interfaces in a query processing for persistent object bases; (2) design of a logical object algebra for the parser/optimizer interface; (3) design for a query processing language for the optimizer evaluator interface; (4) structure and specification techniques for the query optimizer components itself, in particular automatic generation of

Engineering, The University of Alabama, P.O. Box 870286, Tuscaloosa, Alabama 35487-0286. The Search Committee will begin considering applications November 1, 1993 and will continue until the positions are filled. Female and minority candidates are strongly encouraged to apply. The University of Alabama is an Equal Opportunity/Affirmative Action employer.

Hong Kong University of Science and Technology - Department of Electrical & Electriconic Engineering invites applications for tenure-track faculty positions for all ranks including Lecturer, Senior Lecturer, Reader and Professor starting 1 July, 1994. The EEE Department at this new university is currently in its third year of operation with approximately 400 UG and 100 PG students. The Department has 32 full-time faculty in the 1993-94 academic year and is planning to expand to over 40 faculty for the 1994-95 academic year. The Department has major research interests in Microelectronics and in Information and Systems. Of particular interests in the Electronics area include VLSI Circuits Design and Tests, Semiconductor Materials and Devices, Microelectronics, Photonics and Optoelectronics, Optical Information Processing, Microwave Electronics, Microsensors and Nanotechnology. Of interests in the Information and Systems areas include Circuits and Systems Theory, Signal Processing, Wireless Communications, Video Technology, Networking, Robotics and CAD/CAM. We are also very interested in applicants in the areas of Computer Engineering, Computer Architecture, Computer Hardware and Computer Design. We are also interested in applicants with expertise in Biomedical Sensors, Biomedical Signal Processing and Biomedical Instrumentation. Applicant should have a PhD with demonstrable experience in teaching and research. The Department has excellent facilities for teaching and research and the University has excellent central facilities including a complete microelectronics fabrication centre and a well-equipped material preparation and characterization centre. Salaries are paid on 12 months basis and monthly salary ranges between HKD 30,000 to 50,000 for Lecturer, HKD 48,000 to 70,000 for Senior Lecturer and Reader and a minimum of HKD 72,000 for Professor with generous benefits such as 6 weeks of paid annual leave, two weeks of short leave, senior staff quarters and private tenancy allowance for junior staff, medical and dental insurance and others. Initial appointments are for 3-year term with a 25% gratuity of total salary paid upon completion of contract. Applications including curriculum vitae, list of publication and names and addresses of 5 ref-

be sent to: Professor Peter Che-
partment of Electrical & Electronic
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iversity of Science and Technol-
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enings for Chief Technician, Sen-
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area. Advanced degree and in-
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clude assisting faculty in teaching
the areas of basic electronics,
s, semiconductor device fabrica-
zation and testing, electro-optics,
VLSI circuits design, wireless
s, networking, video technology,
and CAD/CAM. The Chief Tech-
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onstrator is a full time position to
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ranges from: Chief Technician:
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00, Technician: HKD 12,000 to
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d names and addresses of 3 references should be sent to: Professor Peter Cheung, Head, Department of Electrical and Electronic Engineering, Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong.

Analog Microelectronics Faculty Position: Texas A&M University seeks a faculty member in the area of Analog VLSI Microelectronics Circuits. Duties include teaching undergraduate and graduate courses, and doing research in the analog circuit area of specialization. This is a one year visiting position with potential to be converted into a tenure track position. Rank and salary will be commensurate with qualifications. The Electrical Engineering Department has about 1200 undergraduate students, 450 graduate students, and a faculty of 49. College Station is located less than two hours driving distance from both Austin and Houston. Applications and inquiries should be directed to: Dr. Edgar Sanchez-Sinencio, Department of Electrical Engineering, Texas A&M University, College Station, Texas 77843-3128, (409) 845-7498. Texas A&M University is an affirmative action, equal opportunity employer.

Faculty Position-The Center for Microelectronics Research (CMR) at the University of South Florida invites applications for a tenure-track Assistant Professor position beginning in January 1994. Applicants should have an earned doctorate, a minimum 5 years industrial experience and a record of outstanding university research in the field of silicon microelectronics materials and processing, including: advanced CMOS processing, manufacturing and research specifically related to microcontamination effects on material defects structures, devices, yield analysis and modeling; silicon defect recognition and imaging through optical and electrical characterization; research pertinent to trace metal impurity interaction with advanced silicon ULSI devices; hands-on experience in maintaining cleanroom operating systems. The applicant must possess a proven track record in generating winning proposals and successful contract performance. The applicant will be expected to develop a strong funded research program in his/her area of expertise and teach at least one course per semester. CMR has an excellent microelectronics cleanroom with furnace and RTP thermal process capability, LPCVD, PECVD, RIE and ECR plasma processing capability, plus well equipped materials and device engineering laboratories. USF is an Affirmative Action/Equal Opportunity Employer. Applications should be directed to Dr. Earl J. Claire, CMR, M/S ENB-

West Virginia University, P.O. B
gantown, WV 26506-6101. App
received and considered im
searches will continue until all ava
are filled. West Virginia Universit
tive action/equal opportunity emp

The Department of Electrica
North Carolina Agricultural and
University, invites applications
faculty positions at all ranks in th
of computer engineering, micro
control systems, and solid state
devices. Applicants must have a
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teaching and research accon
potential. Academic duties incluc
developing undergraduate and gr
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Ph.D. degree program. The maj
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of North Carolina system, and is
member of the Microelectronics
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qualifications. Interested applica
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Ward Collis, Faculty Search Committee, Department of Electrical Engineering, North Carolina A&T State University, Greensboro, NC 27411, no later than October 15, 1993. North Carolina A&T State University is an affirmative action, equal opportunity employer.

Faculty Position in Electrical Engineering - The Faculte des sciences appliquees of the Universite de Sherbrooke, Quebec, Canada, invites applications for a tenure-track faculty position in electrical engineering. General responsibilities - Teaching at undergraduate and graduate levels, specialized research in electrical engineering, graduate students supervision and training, course and program management and community involvement. General qualifications - Ph.D. in electrical engineering; excellent communication skill, strong commitment to teaching, research and technology transfer; excellent knowledge of written and spoken French; qualifications to become member of the Ordre des ingenieurs du Quebec. Specific qualifications - Specialization in the design of analog and digital electronics systems; meaningful design experience of ASIC circuits and gate array technologies. Candidates should send their resume and c.v. before October 4, to: The Dean, 93-1-23, Faculte des sciences appliquees, Universite de Sherbrooke, Sherbrooke, Quebec, Canada J1K 2R1. Salary and working conditions are in accordance with the terms of the current collective agreement. The Universite de Sherbrooke is an equal opportunity employer and encourages applications from qualified women. In accordance with Canadian immigration requirements, this advertisement is directed in the first instance to Canadian citizens and permanent residents of Canada.

New Program in Computer Engineering. Department of Electrical Engineering, South Dakota School of Mines & Technology: Continuation of Faculty Search. Applications are invited for an Assistant or Associate Professor level, tenure track faculty position in the area of Computer Engineering. The school has a new program leading to a B.S. degree in Computer Engineering and the successful candidate will be involved in developing this new program. It is expected that the position will be filled by January 1, 1994, but the search will remain open until the position is filled. Duties will include developing and teaching undergraduate courses in the new Computer Engineering program, teaching undergraduate and graduate courses in the Electrical Engineering program, promoting and developing research, and directing research of graduate stu-

field. Desirable areas of concentration are neural networks, pattern recognition, and virtual reality. In addition to regular teaching and service responsibilities, the faculty member in this position is expected to build a strong research program in his/her area of specialization. Preference will be given to those individuals with proven leadership abilities in building research programs; some industrial experience is also desirable. Resume and a list of three (3) references must be received by mail, by October 31, 1993. Send to: Prof. Don Hush, Search Committee Chair, Electrical and Computer Engineering Department, The University of New Mexico, Albuquerque, NM 87131. The University of New Mexico is an Equal Opportunity/Affirmative Action Employer.

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Kansas is an affirmative action/equal opportunity employer.

Virginia Tech, Faculty Positions in Electrical Engineering. The Bradley Department of Electrical Engineering of Virginia Polytechnic Institute and State University (Virginia Tech) invites applications for tenure track faculty positions at the Assistant Professor level. Needs are in the areas of (1) optoelectronic devices and materials with emphasis on thin film applications and fiber optics, (2) high frequency power semiconductor devices with emphasis on electronic materials, device design and fabrication, smart devices, and applications, and (3) intelligent, adaptive, and learning control along with sensor-based robot control. Applicants must have a doctorate in Electrical Engineering, be interested in undergraduate, and graduate teaching, and be willing to secure research sponsorship. Virginia Tech is Virginia's land grant university offering degrees through the Ph.D. Send complete resume with references and employment/citizenship status to: Prof. Gary S. Brown, Search Committee, Bradley Department of Electrical Engineering, Virginia Tech, Blacksburg, VA 24061-0111. Applications will be accepted until 15 December, 1993, or until suitable candidates are selected. Virginia Tech has a strong commitment to the principle of diversity and, in that spirit, seeks a broad spectrum of candidates including women, people of color, and people with disabilities. Individuals with disabilities desiring accommodation in the application process should notify Kathy Atkins, Electrical Engineering Department, at 703-231-4136 or TDD/PC - 1-800-828-1120 or Voice - 1-800-828-1140 by 15 December 1993.

The Center for Laser Science and Engineering at the University of Iowa anticipates the availability of a limited number of temporary post doctoral research positions in the general areas of photonics and quantum electronics. Salary will commensurate with the qualifications and experience of the candidate. Preferred areas of interest include (but are not limited to) blue-green and ultraviolet materials and devices; optical communications; atmospheric propagation; development of ultrafast lasers; strong-field science and applications; ultrafast investigations of processes, materials and devices; growth, fabrication, and characterization of traditional and non-traditional photonic materials and devices; and photonics engineering. The search will remain open until all positions are filled. Women and minorities are encouraged to apply. Applicants should send a complete vitae and the names of three references to: Post Doctoral Screening Committee, Center for Laser Science and Engineering, 144 Iowa Advanced Technology Laboratories, University of Iowa, Iowa City, Iowa 52242-1000. (319) 335-3461. The University of Iowa is an Equal Opportunity/Affirmative Action Employer.

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The University of Alabama invites applications for two tenure-track faculty positions in the Department of Electrical Engineering at the Assistant Professor level. Departmental needs are in the areas of computer engineering and control systems, although outstanding candidates in other areas will be considered. Duties include both teaching and research activities. All faculty members are expected to develop externally funded research programs involving graduate students. Applicants must have an earned doctorate in Electrical or Computer Engineering, or in a closely related field. U.S. citizenship or permanent resident status is required for a tenure track appointment. Salary is commensurate with qualifications. Send a resume to Dr. Russell L. Pimmel, Department of Electrical Engineering, The University of Alabama, P.O. Box 870286, Tuscaloosa, Alabama 35487-0286. The Search Committee will begin considering applications November 1, 1993 and will continue until the positions are filled. Female and minority candidates are strongly encouraged to apply. The University of Alabama is an Equal Opportunity/Affirmative Action employer.

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Hong Kong University of Science and Technology - Department of Electrical & Electriconic Engineering invites application for research and teaching support staff. The Department currently has different openings for Chief Technician, Senior Technician, Technician, Demonstrator and Research Assistant. Applicants should have a BS degree in Science or Engineering in a relevant technical area. Advanced degree and industrial experience are highly desirable. Responsibilities include assisting faculty in teaching and research in the areas of basic electronics, microprocessors, semiconductor device fabrication, characterization and testing, electro-optics, microsensors, VLSI circuits design, wireless communications, networking, video technology, robotics, control and CAD/CAM. The Chief Technician is expected to have substantial managerial experience and act as manager for all technical staff and technical services for the Department. The Demonstrator is a full time position to assist in UG teaching including tutorials and laboratories. Research Assistant is full time position to assist in faculty research. Approximate monthly salary ranges from: Chief Technician: HKD 25,000 to 30,000, Senior Technician: HKD 18,000 to 24,000, Technician: HKD 12,000 to 20,000, Demonstrator: HKD 18,000 to 21,000, Research Assistant: HKD 8,000 to 20,000. The University provides attractive benefits including medical and dental coverage, private tenancy assistance based on qualifications and post, and superannuation, etc. Application including complete resume and names and addresses of 3 references should be sent to: Professor Peter Cheung, Head, Department of Electrical and Electronic Engineering, Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong.

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118, University of South Florida, 4202 E. Fowler Ave., Tampa, FL 33620 by October 15, 1993.

Graduate Research Assistants. The Center for Microelectronics Research (CMR) at the University of South Florida is seeking graduate research assistants to support research activities in the areas of VLSI/ULSI/WSI/MCM architecture, circuit design, rapid prototyping and test; microelectronic materials and defects and semiconductor processing and manufacturing. Successful applicants will be required to pursue an MS or Ph.D. program in E.E., C.S.&E., or Engineering Science. Excellent stipends are available for half-time research support for a full calendar year beginning January 1994 or August 1994 with tuition waivers available. Applicants must have an excellent academic record and a minimum of a Bachelors degree in an appropriate discipline. U.S. Citizenship is a requirement for most current and anticipated positions. CMR has an expanding program of funded research and seven new research laboratories. USF is an Affirmative Action/Equal Opportunity Employer. Resumes to Dr. Earl Claire, Director, CMR/USF,M/S ENG 118, 4202 E. Fowler Avenue, Tampa, FL 33620.

University of Bradford, UK: Chair in Real-Time Electronic Systems, Department of Electronic and Electrical Engineering. Applications are invited from candidates with a strong research record, gained from working either in industry or in university. This is one of 3 full professorships in the Department, which includes 36 academic staff, 70 research and support staff, 350 undergraduates and 100 graduate students. The Department is ranked in the top 20 of 64 UK universities in terms of research funding, in the recent UK government research selectivity assessment. We enjoy good national and international reputations in the fields of telecommunications, solid state and optoelectronics. We now seek to strengthen our research leadership in the area of Real-Time Electronic Systems, in which approximately 11 of our staff are engaged, several of whom are young and just beginning to establish their research careers. Existing areas of specialization within Real-Time Electronics include: Advanced Processor Architectures, Imaging Systems, Signal Processing, Power Electronics, Robotics and Control, Safety-Critical Systems and Energy Management. We would expect the successful candidate to relate to one or more of these areas. Further particulars are available from Mr. P.M. Bunting, Head of Personnel (Ref CEE/IEEE), University of Bradford, Bradford, West Yorkshire BD7 1DP, UK. Informal enquiries may be made to Professor Peter Watson, tel +44 274 384002, fax +44 274 385300 to whom applications including full CV should be returned by 15 October 1993. Working towards Equal Opportunities.

The University of Zurich and the Federal Institute of Technology in Zurich invite applications for the tenured position of a Professor of Theoretical Neuroinformatics who will be the head of the Section of Theoretical Neuroinformatics in a new Institute of Neuroinformatics which is jointly established by the University of Zurich and the Federal Institute of Technology in Zurich (ETHZ). The new Institute will consist initially of the Section of Systems Neurophysiology and the Section of Theoretical Neuroinformatics, and will be later supplemented by the Section of Technical Neuroinformatics. The research will focus on information processing in real and artificial neural networks, and on the study of interfaces between electronic and neuronal substrates. The Section of Theoretical Neuroinformatics will investigate information processing in biological neural networks and in artificial systems that are related to the structure and function of the brain. A main focus will be the study of highly parallel processes to gain insights into brain functions. Of particular interest are adaptive systems exhibiting features of self-organization; algorithms for pattern recognition, motor control, learning and memory; and the analysis of non-linear systems that are relevant for the neurosciences. The Professor of Theoretical Neuroinformatics will be appointed jointly by the University and the ETHZ and will be expected to conduct innovative, high-standard research in his/her specific area, in close collaboration with the other Sections of the Institute. The teaching duties will include courses on the graduate and postgraduate level (non-German speaking candidates will be expected to acquire sufficient language skills within a reasonable time period). Candidates with an outstanding research record are invited to send their application before 30 September 1993 to the Chairman of the Search Committee, Prof. A. Borbely, Institute of Pharmacology, University of Zurich, Gloriastrasse 32, CH-8006 Zurich, Switzerland; Fax +41-1-261-5684 (after 18 Sept. +41-1-257-5707). Material to be submitted: C.V., list of publications (those published in peer-reviewed journals listed separately) and 5-10 reprints.

Assistant Professor of Medicine and Biomedical Engineering. Applications are being accepted for a tenure-track position in the Departments of Medicine and Biomedical Engineering at Case Western Reserve University School of Medicine. Applicants should have proven record of research/publication, with demonstrated ability or potential to develop major research lab in collaboration with medical scientists/clinicians, and to obtain extramural funding. Candidates must hold a Ph.D. in Engineering. Seeking individual with expertise related to endoscopic imaging. Responsibilities include teaching graduates and undergraduates and supervision of graduate student research. Forward CV, and names of 3 individuals who can provide letters of reference to: Michael V. Sivak, Jr., M.D., Chief, Div. of Gastroenterology, University Hospitals of Cleveland, 2074 Abington Road, Cleveland, Ohio 44106. The University is an Equal Opportunity/Affirmative Action Employer.

Position Available - School Head, Electrical and Computer Engineering. Nominations and applications are invited for the position of Head, School of Electrical and Computer Engineering, Oklahoma State University. Qualifications sought include an earned doctorate and a national reputation in electrical or computer engineering. A candidate should have a distinguished record in research, publications, and external funding, a strong interest in educational programs at both the graduate and undergraduate level, a record of participation in professional societies, and demonstrated leadership ability. Registration as a Professional Engineer is desired. Appointment to this position confers tenure at the professor level; the successful candidate must qualify for appointment as Professor of Electrical and Computer Engineering. The School of Electrical and Computer Engineering has 20 faculty. It offers degrees at the bachelor's, master's and doctorate levels. An active research program is conducted with significant external support. Applications including a detailed resume, references, and a statement of capabilities and qualifications should be received prior to November 1, 1993, to receive full consideration. Please send applications or nominations to: School Head Search Committee, School of Electrical and Computer Engineering, 202 Engineering South, Oklahoma State University, Stillwater, OK 74078-0321. OSU is an affirmative action equal opportunity employer.

Chair, Department of Electrical Engineering, University of North Florida - UNF seeks a dynamic person to lead the developing EE Department. The current focus is on enrollment growth and preparation for ABET accreditation. Academic emphasis is on computer engineering and systems design, specializing in communications and robotics. Requirements are Ph.D. in EE or related field, credentials commensurate with a tenured faculty appointment at the level of professor, and demonstrated teaching excellence. Other considerations include proven leadership and administrative skills, proven research skills, experience with ABET accreditation process, and professional registration. The Chair is a 12-month position; starting date January, 1994 or negotiable. UNF, a growing institution in the State University System, enrolls 10,000 students and is especially committed to excellence in undergraduate education and selected graduate programs. Send letter of application, vita, and three letters of recommendation by October 15, 1993 to Dr. Leonard Lipkin, EE, Chair Search, Dept. of Mathematics and Statistics, University of North Florida, 4567 St. Johns Bluff Rd., Jacksonville, FL 32224-2645, (904)646-2653, Fax (904) 646-2988, LLIPKIN@unf1vm.bitnet. UNF is an Equal Opportunity/Equal Access/Affirmative Action employer.

Electrical Engineering: The University of Portland seeks a faculty member specialized in at least one of the following areas: 1) analog and digital circuit design, 2) high speed electronic systems, 3) circuit simulation, and 4) instrumentation. Ph.D. in Electrical Engineering is required, dedication to excellence in teaching is essential. Duties include teaching undergraduate and graduate courses, laboratory development, and scholarship activities in the area of specialization. Tenure track position, Assistant or Associate rank. Send resume and names of at least three references to: EE Search Committee, School of Engineering, University of Portland, 5000 N. Willamette Blvd., Portland, OR 97203. (503) 283-7314. An affirmative action/equal opportunity employer.

Graduate Research Assistantship: Hardware/Software design of ATM network switches, line interfaces and protocols using gigabit VLSI and optoelectronics. The work involves optoelectronics, VLSI design, VHDL programming, computer networking and state-of-the-art CAD tools (Synopsys VHDL, Comdisco Signal Processing Workbench and CASCADE Automation silicon compiler). This assistantship will be funded by the DoD through the AASERT program, thus US citizenship is required. Student will be expected to pursue a PhD degree. Contact Prof. Fouad Kiamilev at the University of North Carolina at Charlotte, Dept. of Electrical Engineering, Charlotte, NC 28223, or email: kiamilev@mosaic.uncc.edu. UNCC has a strong institutional commitment to the principles of diversity. In that spirit we are particularly interested in receiving applications from women, members of ethnic minorities, and disabled individuals.

Lehigh University, Faculty Position in Computer Science. The Department of Electrical Engineering and Computer Science at Lehigh University seeks applicants in networking and software systems for a tenure track computer science faculty position. Candidates must have a PhD in computer science or a PhD in electrical engineering with appropriate networking background. We require a strong commitment to teaching and evidence of innovative research through journal publications. Preference will be given to junior faculty, but we would consider senior faculty with an impressive record of publication and funding in the fields of interest. The Department has an expanding Computer Science Division with excellent facilities and offering BA, BS, MS and PhD degrees in Computer Science. Lehigh University has a 127-year history of excellence in engineering and technology indicated by high national rankings. The University is located on an attractive 1,600-acre mountainside campus in Bethlehem, Pennsylvania, close to the Pocono Mountains and within easy reach of Philadelphia and New York City. Send e-mail to eecs@eecs.lehigh.edu for further information about the Department. Lehigh University is an affirmative action/equal opportunity employer. Women and minorities are encouraged to apply. Candidates should send a curriculum vita and at least three references to Dr. Alastair McAulay, Chair and Chandler Weaver Professor, Faculty Search Committee, Department of Electrical Engineering and Computer Science, Lehigh University, 19 Memorial Drive West, Bethlehem, Pennsylvania 18015.

Rensselaer Polytechnic Institute - The Signal and Speech Research Group invites applications for a Post-Doctoral Research Position. Strong background in Speech and Signal Processing theory and hardware necessary. An earned PhD in engineering or science is required. Duties and Responsibilities: Conduct research in Speech and Signal Processing in collaboration with other investigators. Develop software as needed, participate in the preparation of proposals, research reports and other publications. Supervise graduate students. Appointment is for one year with the possibility for extension. US Citizenship required. Please send your resume and the names

of three references (no calls) by September 20, 1993 to professor Michael Savic, ECSE Dept., Rensselaer Polytechnic Institute, Troy, NY 12180-3590. Rensselaer is an Equal Opportunity/Affirmative Action Employer.

Biomedical Engineering. Graduate programs leading to MSc and PhD degrees. Research and Teaching assistantships available to suitably qualified students. Excellent research opportunities in: In-vivo NMR; Rehabilitation Eng; FES; Urodynamics; Signal Processing. Further details: Prof Z. Koles, Dept of Applied Sciences in Medicine, University of Alberta, Edmonton, Canada T6G 2G3. Fax (403) 492-8259.

Postdoctoral Research Associate: The Center for Aviation Systems Reliability seeks a candidate for research and development in eddy current NDE. The successful candidate will be expected to carry out a government-sponsored project for basic technology development in collaboration with industrial participants. The required qualifications for this position include: 1) Ph.D. in either electrical engineering or physics; 2) detailed knowledge of electromagnetic theory; 3) demonstrated ability in solving differential equations via numerical algorithms, preferably by the boundary element method, and 4) experience in writing user-friendly code in UNIX environment using the C language (preferably in C++). Send cover letter, resume, plus the names and addresses of three references to: Ames Laboratory/IPRT Personnel Office, 127 Spedding Hall, Iowa State University, Ames, IA 50011. Iowa State University is an equal opportunity/affirmative action employer.

Old Dominion University. The Department of Electrical and Computer Engineering invites applications for a tenure-track position in computer engineering. The position is anticipated to be filled at the assistant professor level beginning January 1, 1994. Desired areas include fault-tolerant computing, parallel and distributed systems, real-time computing, digital design, and computer networks. Applicants must have an earned doctorate in electrical or computer engineering. Duties include undergraduate and graduate teaching, supervision of graduate students, and development of a program of sponsored research. Send complete resume with references and employment/citizenship status to: Dr. Roland Mielke, Chairman, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, Virginia 23529-0246. Applications will be accepted until October 1, 1993, or until a suitable candidate is selected. Old Dominion University is an affirmative action, equal opportunity employer and requires compliance with the Immigration Reform and Control Act of 1986.

Government/Industry Positions Open

Design Engineer. Will work with semiconductor device structure and fabrication process and use QNX distributed real-time operating system to design, modify, develop, and test instruments and systems for automating the manufacturing process of semiconductor facilities. Requires Ph.D. in Electrical Engineering with one year of graduate research experience in semiconductor device structure and fabrication process and in QNX. Must have legal authority to work in the U.S. This full-time position pays $48,000 per year. Job site and interview in Vancouver, WA. By October 1, 1993, send resume to: Employment Security Department, E&T Division, Job #381264, Post Office Box 9046, Olympia, WA 98507-9046.

Sr. Computer Engineer for SW Ohio R & D contractor. Design, analyze and implement computer and computer system architectures in support of company's contract work and internal research and development. Will be principal investigator for projects, products and services involving Very High Speed Integrated Circuit Hardware Description Language, parallel discrete event simulators and object-oriented design and programming. M.S. Degree in Computer Engineering with emphasis in Computer System Design. Two (2) years experience required. Experience may have been gained at any time and must have involved: use of Very High Speed Integrated Circuit Hardware Description Language; design, analysis and Implementation of a parallel discrete event simulator. Included in the 2 years experience must have been 1 year in object-oriented design and programming. All experience may have been acquired concurrently. 40 hr/wk. 8:00 to 5:00, $20.28 to $28.00 per hour (depending on qualifications). Must have proof of legal authority to work indefinitely in U.S. Qualified applicants send resume in duplicate (no calls) to J. Davies, JO#1382799, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216.

Development Staff Member (Tucson, AZ). Perform research and development of advanced digital control systems for computer tape and optical drive products. Design, simulate, and evaluate digital control systems utilizing Matrixx simulation tools for design optimization, and implement accompanying hardware and software. Ph.D. in Electrical Engineering plus 1 year in job or 1 year as a Graduate or Post-graduate Research Assistant. One year experience in related occupation must include research in the area of advanced digital control systems including the development of real time computer programs in C language on digital control, design & simulation of control systems using Matrixx tools, and robust mathematical modeling for control system design. Must have knowledge of neural networks and fuzzy logic as evidenced by course work or employment experience. 40hr/wk; 7:30 a.m.-4:12 p.m.; $55,008/yr. Qualified applicants should submit resume or application letter with ad to: AZ DES Job Service, Attn: 732A, Re: 0084387, P.O. Box 6123, Phoenix, AZ 85005. Job Location: Tucson, Arizona. Emp. pd ad. Proof of authorization to work in U.S. required if hired.

International Employment Opportunity. Project HOPE, an independent, international nonprofit health education organization, is implementing a multi-disciplinary education program for health care providers in Kazakhstan. Its focus will be preventive and primary care for infants and mothers, TB management, cardiac care and biomedical engineering. Staffing needs are ongoing over the next five years for long and short-term Biomedical Engineers. Knowledge of the Russian language is preferred. To learn more about this exciting opportunity, contact Project HOPE, International Recruitment Section, Millwood, VA 22646. 1-800-544-4673. EOE. M/F/H/V.

Electrical Engineer P.E. for Florida Consulting Firm. Commercial/Hospital experience a must. Partnership potential. Write: Emtec Corporation, 250 Bird Road, Suite 200, Coral Gables, FL 33146. Fax: (305) 461-3390

The Center for Remote Sensing is a small organization involved in space science R&D. Engineers and scientists with degrees in physics, electronics, and/or computer science with specialization or experience in any of the following are needed: (1) Hardware and/or software related to DSP and PC machine level (Real time signal processing and advanced graphics with C is essential for those with software experience; experience with various image processing tools relevant to object identification and trace recovery would be beneficial); (2) e.m. modeling using FEM; (3) All aspects of LAN/WAN and familiarity with Internet, ATM X.25, and related areas; (4) Instrumentation related to interferometry, fiber optics, lidar, and modern optical systems; and (5) Analog and digital instrumentation and RF and Microwave systems development. Full and part-time positions are available. Responses should include a detailed resume, acceptable salary, and availability. Excellent benefits are available. CRS is an equal opportunity employer. Write to: CRS Employment, P.O. 9244, McLean, VA 22102.

Senior Electrical Engineer, Hydroelectric Power Systems: Will establish and prepare entire electrical power system portion of engineering company's proposals relating to construction of major hydroelectrical projects in Latin America. Will review design of specific power generators and transformers to be installed as part of such hydroelectric power systems in Latin America and will assure that design is in conformity and integrated with overall power system design. Will review and establish procedures for calculation and drawings of electrical design. Evaluate, review, and test equipment of suppliers of electrical equipment to be installed in hydroelectric power plants . Work to be performed will relate to all phases (design, construction, and start-up) of hydroelectric power plants in Latin America. Will travel 40% of time to Latin America. Requires B.S. degree in Mechanical, Electrical or Electrical and Mechanical Engineering. Also requires eight years of experience in the job to be performed. Must speak and read Spanish. Hours: 8:15 a.m. - 5:00 p.m. 40 hours per week at $37.50 per hour salary. Must have proof of legal authority to work permanently in the U.S. Please send resume to: Illinois Department of Employment Security, 401 S. State St. - 3 South, Chicago, IL 60605, Attn: Dennis P. Jones, Ref. #V-IL 10679-0, No Calls, 2 copies of your resume required, An Employer Paid Ad.

EEsof Incorporated is expanding its Technical Staff! Join our engineers in creating high frequency analog software that continually challenges current standards for case-of-use productivity. Current openings include: 1) MTS, responsible for the design, development, and maintenance of RF/MW synthesis tools. Requires: MSEE or Ph.D in EE or CS; exp. in design automation or analog/RF/MW circuit and system design; "C"; UNIX; knowledge of analog/RF/MW synthesis and exp. w/Libra and/or Omnisys desirable. 2) MTS, responsible for the design and development of electromagnetic simulation tools for analysis of MMIC circuits and their pkgs. Requires: MSEE or Ph.D EE with a concentration on the numeric solution of EM problems; exp. in implementation and application of EM simulators for circuits, time-& frequency-domain methods, and "C". EEsof offers competitive compensation and full benefits in a successful, rapidly-growing company. If qualified, send resumes (principals only), in confidence, to: EEsof, Attn: IEEE-993, 5601 Lindero Cyn. Rd., Westlake Village, CA 91362. Or fax to: 818/879-6212.

Leading eng & construction firm has immed need for Sr Electrical Engineer who will function as the Lead Eng & supervise/oversee the dsgn & engineering of elec power systems as applied to petroleum & petrochem facilities, utility facilities & switchyards, industrial-utility interconnections & power generating stations. Will ensure the tech adequacy & timely completion of all related work in accordance w/American standards & safety regulations such as ANSI, IEEE, NEC, API & NESC for U.S. domestic jobs & w/intl industry standards such as IEC & BS for overseas projects. Specific responsibilities incl: Preparing elec equip specifications & tech documents (incl prep of project elec design basis, transmission sys & relaying specs) using overcurrent grading coordination of protective relay devices; Performing protective relay dsgn philosophy for utility-refinery & cogenerational interconnections & performing relay coordination, short circuit, load flow & motor starting power sys studies using DAPPER, CAPTOR and AFAULT software pkgs in accordance w/IEEE standards; Preparing eng & dsgn deliverables lists; Forecasting discipline staffing requirements & preparing electrical engineering discipline execution schedules; Preparing discipline progress & status reports for the Proj Eng; Performing eng & construction cost estimates related to the electric scope of work; Dev 1 line diagrams using overcurrent grading coordination of protective relay sys & electrical hazardous area classifications in accordance w/domestic (NEC, API, NFPA) & intl applicable standards (IEC); Dev personal computer programs for short circuit analysis & relay coordination studies; Supervising use of microcomputer work station & allocation of software; Preparing purchase requisitions for major elec equip; Reviewing vendor drawings & tech documentation for compliance w/industry standards, project tech specs & safety regs; Procurement of eng & dsgn info from vendors & outside consultants/in-house specialists; Interfacing w/engineers & designers to produce eng drawings & dsgns; Interfacing w/in-house marketing to produce eng proposals & participating in presentations to clients; Training & providing tech & administrative guidance to 2-12 support engineers & dsgnrs & Performing interdisciplinary coordination to resolve problem areas. A qualified candidate must have a Bachelor's degree in Elec Eng plus at least 8 yrs exp in the position offered or 8 yrs exp with electrical services engineering for the

petroleum, petrochemical, industrial & electric utility industries. This exp must incl 5 yrs exp as a Sr or Lead Electrical Engineer performing any of the following activities: protective relay studies, preparation of engineering deliverables estimates, forecasting of discipline staffing, supervision of a technical group of engineers & designers, & preparation of schedules & reports for Project Engineers. Salary is $58,894 - $62,100 per year for a 40+ hour work week. Apply at the Texas Employment Commission, Houston, Texas, J.O. #TX6343009 or send resume to the Texas Employment Commission, TEC Building, Austin, Texas 78778, J.O. #TX 6343009. Ad paid by an Equal Opportunity Employer.

Device Engineer II position available in Hillsboro, OR. Will solve complex device performance problems on submicron E2CMOS technology through electrical and physical analysis of semiconductor wafers. Perform detailed analysis of semiconductor device electrical performance. Perform semiconductor parameter extraction and build models to match actual device performance . Identify fundamental causes for device performance deviations from modeled parameters. Develop new test structures and test methodologies. Develop statistical analysis procedures. Document device characterization methods and test procedures for Company products. Education: Masters degree in Electrical Engineering required. Experience: No experience necessary. Special Requirements: 3 years experience to include: 1) detailed understanding of semiconductor device physics, as demonstrated by 3 years experience in MOS devices; 2) In depth knowledge of semiconductor device fabrication processes such as Si oxidation, diffusion, lithography, metallization, RTA, spreading resistance, as demonstrated by 3 years experience; 3) Familiarity with semiconductor device characterization equipment including high precision current meters, LCR meters, parameter analyzers, SEMs, GV & G-V characterization of MOS-type devices, as demonstrated by 3 years experience; 4) Extensive experience in programming in Fortran, C, HP-Basic, UNIX and VMS and DOS operating systems, as demonstrated by 2 years experience. Experience may have been gained concurrently and with education. Salary: $51,228/yr. Applicant must have legal authority to permanently work in the U.S. Send resume to Employment Division, Attn: Job Order 5550543, 875 Union Street NE, Room 201, Salem, OR 97311.

Product engineer position available in Hillsboro, Oregon. Will perform engineering support in all phases of the lifecycles of new company products, from initial definition through standard milestones such as design, fabrication, characterization and test, production and customer support. Provide product development and engineering support of new products. Perform validation, design modifications to existing new products and design process enhancements to standard products. Responsible for Validation, Characterization and transfer to manufacturing of new products. Define test requirements and order all test hardware. Perform software development (all Impact test code and SAS data analysis code), low yield analysis (including SORT and package test), bench data gathering, wafer/lot logistics from E-Test through qualification, reports generated per current Time-To-Market strategies. Organize and hold weekly team meetings and publish minutes. Perform engineering support on taskforces for fault analysis on all products. Education: Bachelor's of Science Degree in Electrical Engineering. Experience: None required. Special Requirements: Experience to include: Two years experience in Fault diagnosis and Fault Tolerance; three years experience in Digital and VLSI Design. Familiarity with standard lab equipment including high speed setups, oscilloscopes, pulse generators, power supplies, DVM's, Data generators, micro-probing stations, etc.) as demonstrated by two years experience. Experience may have been gained concurrently with education. Salary: $38,724 per year. Applicant must have legal authority to permanently work in the U.S. Send resume to Employment Division, Attn: Job Order 5550507, 875 Union Street NE, Room 201, Salem, OR 97311.

NATIONAL UNIVERSITY OF SINGAPORE

DEPARTMENT OF ELECTRICAL ENGINEERING

The Department of Electrical Engineering invites applications for **teaching appointments** from candidates with a PhD degree in one of the following areas:

Adaptive Control	**Power System Protection**
Computer Communications	**Power Electronics/Smart Power Devices**
Operating Systems	**Real-time Computing**
Optical Fibre Communications (Experimentalist)	**Microelectric Device Technology**
	VLSI Design
Parallel and Distributed Systems	**Microwave and RF Engineering**

Besides appointments on normal 3-year contracts, **visiting appointments** for one or two years may be considered.

Gross annual emoluments range as follows:

Lecturer	S$54,330 – 65,620
Senior Lecturer	S$59,970 – 106,030
Associate Professor	S$93,700 – 129,870

(US$1.00 = S$1.61 approximately)

The commencing salary will depend on the candidate's qualifications, experience and the level of appointment offered. In addition, a 13th month allowance and an Annual Variable Component may be payable under the flexible wage system applicable to staff on normal contracts.

Leave and medical benefits will be provided. Depending on the type of contract offered, other benefits may include: provident fund benefits or an end-of-contract gratuity, a settling-in allowance of S$1,000 or S$2,000, subsidised housing or a housing allowance, education allowance for up to three children subject to a maximum of S$16,425 per annum per child, passage assistance and baggage allowance for the transportation of personal effects to Singapore. Staff members may undertake consultation work, subject to the approval of the University, and retain consultation fees up to a maximum of 60% of their gross annual emoluments in a calendar year.

The Electrical Engineering Department has currently an academic staff strength of 71 with 21 laboratories, all of which have excellent facilities for teaching and research. In addition, there are three externally funded research centres: Centre for Optoelectronics, Centre for IC Failure Analysis and Reliability and the Magnetics Technology Centre. Facilities include a Riber 32P Molecular Beam Epitaxy System and 2 liquid phase epitaxy systems for research into III—V compound devices. A wide range of computing resources are available, including numerous PCs, SUN SparcSS10-30s, HP 715s and IBM RS/6000.The University Computer Centre operates an IBM3081 KX2, and has acquired a high-speed campus-wide network directly linking the staff's PCs (now provided to every staff member) to the various computing resources, including 2 supercomputers based in the nearby Science Park. A number of large-scale research projects are in progress, including an optical LAN joint effort with Singapore Telecom and a project to develop VLSI design tools jointly with Chartered Semiconductors. The Department has spearheaded the formation of the national Institute of Microelectronics and has recently been commissioned to establish a national Centre for Wireless Communications.

Application forms and further information on terms and conditions of service may be obtained from:

The Director
Personnel Department
National University of Singapore
10 Kent Ridge Crescent
Singapore 0511

The Director
North America Office
National University of Singapore
55 East 59th Street
New York, N.Y. 10022, U.S.A.
Tel: (212) 751-0331

Enquiries may also be sent through **BITNET** to:
PERLEEMK @ NUS3090,
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New financial program offered to IEEE members

Beginning this month, the IEEE is offering its members a new package of financial services, including mutual funds, loans, and annuities. The IEEE Financial Advantage Program, which eliminates the up to 4.75 percent sales charge that sponsors customarily levy on their mutual funds, was developed over the past year with the assistance of two leaders in the financial services industry: the Vista Capital Management group of the Chase Manhattan Bank, NA, New York City, and Seabury & Smith, Washington, DC.

The program comprises six elements:

• The IEEE Balanced Fund is a mutual fund created just for the IEEE that makes investments in stocks and bonds and seeks to maximize total return on investment by combining long-term capital growth and current income. Minimum investment is US $2500 with additional investments of at least $100. Student members may open an account with as little as $1000 if they agree to invest at least $25 a month.

• The Vista Family of Mutual Funds offers IEEE investors a range of mutual funds with varying objectives and risks. It includes the Vista Growth and Income Fund, which has been ranked the top-performing fund among 801 equity funds for the five years ending June 30, 1993, by Lipper Analytical Services Inc., an independent mutual fund performance monitor. (Past performance is, of course, no guarantee of future success.)

• Annuities, managed by Seabury & Smith, offer fixed and variable options, including portfolios for growth, fixed income, and capital preservation.

• Home financing permits IEEE members to obtain mortgages from Chase Manhattan Home Mortgage Corp. for primary and secondary residences, including cooperatives, condominiums, and vacation homes.

• Automobile financing by Chase Manhattan, with applications for loans taken, and approvals given, over the phone.

• Education financing allows members to choose from multiple options from Chase Manhattan.

Prospective investors in either the IEEE Balanced Fund or the Vista Family of Mutual Funds should call the Financial Advantage Program at 1-800-GET-IEEE (438-4333) for a prospectus that contains complete information about the funds. Members should read it carefully before investing or sending money.

To expedite inquiries, the toll-free number can be reached 24 hours daily, seven days a week. Members may also call this number for information on loans. Annuity information is available by calling 1-800-829-8763.

At present, U.S. tax regulations restrict participation to U.S. members and their immediate families, or to those with a U.S. mailing address and taxpayer identification number. Other products may be added to the program, depending on the response to the current offerings. "We will pay very careful attention to members' comments on the existing features and encourage suggestions about how the program can be expanded," said IEEE executive director and general manager John Powers.

Changed tax status for the IEEE

The IEEE has gained a new tax status from the U.S. Internal Revenue Service (IRS). Contributions—as opposed to dues—to the IEEE and its Sections, Chapters, and Societies are now deductible from members' U.S. income taxes, as charitable contributions. Members' dues continue to be deductible as a business expense for those who qualify. (However, the IEEE recommends that members consult their tax advisors.)

In addition, the IEEE and its Sections can apply separately to individual states for sales tax exemptions on their purchases. Sections requiring guidance in applying for state sales tax exemptions should call the IEEE's director of finance, Michael Sosa, in Piscataway, NJ, at 908-562-5324; fax, 908-932-1193; and e-mail, m.sosa@ieee.org.

Coming
in Spectrum

NEW USES FOR VIRTUAL REALITY. Virtual reality is becoming a reality in more than just video arcade games. This three-part special report describes how three-dimensional viewing systems, computer input devices, and operator tracking systems are solving practical problems in such fields as aerospace, architecture, and medicine. Recent advances in the technology of implementing these systems are also explored.

PLUG-INS FOR SMALL PORTABLES. Next summer, market researchers predict, sales of laptop and notebook computers will top those of the desktop variety. A lack of plug-in slots is a problem for anyone seeking to apply those machines to data acquisition. But there are options, and vendors are beginning to design plug-ins that turn the portables into sophisticated data-acquisition systems.

MAINSTREAMING FLASH MEMORY. Flash memory has recently gone well beyond niche applications and become a widely adopted storage alternative. A manufacturer tells which characteristics should be an engineer's prime concern.

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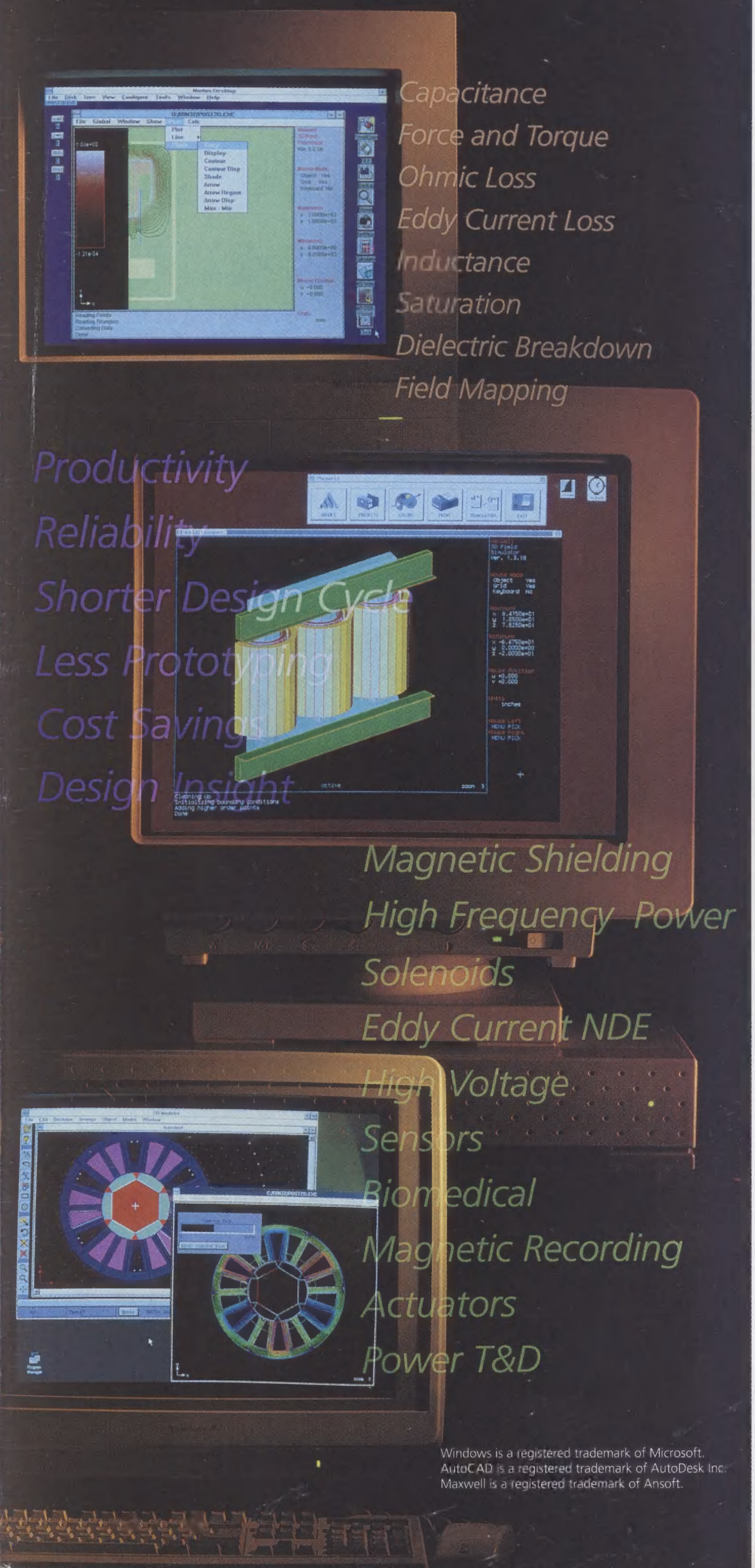

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